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SYSTEM

OF

THEORETICAL AND PRACTICAL

117387

CHEMISTRY,

H.S. [illegible], M.D.
24 N. JEFFERSON ST.
DAYTON, OHIO.

IN TWO VOLUMES, WITH PLATES.

BY FREDRICK ACCUM.
Operative Chemist, Lecturer on Practical Chemistry, and on Mineralogy and Pharmacy; Late Chemical Operator in the Royal Institution of Great Britain.

WITH AN APPENDIX,

CONTAINING

A VIEW OF THE LATE DOCTRINES AND DISCOVERIES

IN CHEMISTRY.

BY THOMAS COOPER, ESQUIRE,
Professor of Chemistry at Dickinson College, Carlisle, Pennsylvania.

VOLUME I.

PHILADELPHIA:
PUBLISHED BY KIMBER AND CONRAD,
NO. 93, MARKET-STREET.
Merritt, printer.
1814.

District of Pennsylvania, to wit:

BE IT REMEMBERED, that on the seventeenth day of December in the thirty-eighth year of the independence of the United States of America, A. D. 1813, Kimber and Conrad of the said district, have deposited in this office the title of a book the right whereof they claim as proprietors in the words following, to wit:

System of Theoretical and Practical Chemistry. In two volumes, with plates. By Fredrick Accum, Operative Chemist, Lecturer on Practical Chemistry, and on Mineralogy and Pharmacy; late Chemical Operator in the Royal Institution of Great Britain. With an Appendix, containing a view of the late Doctrines and discoveries in Chemistry. By Thomas Cooper, Esquire, Professor of Chemistry at Dickinson College, Carlisle, Pennsylvania.

In conformity to the act of the congress of the United States, intituled, "An act for the encouragement of learning, by securing the copies of maps, charts and books, to the authors and proprietors of such copies during the times therein mentioned." And also to the act, entitled, "An act supplementary to an act, entitled "An act for the encouragement of learning, by securing the copies of maps, charts, and books, to the authors and proprietors of such copies during the times therein mentioned," and extending the benefits thereof to the arts of designing, engraving, and etching historical and other prints"

D. CALDWELL,
Clerk of the District of Pennsylvania.

PREFACE.

11, *Old Compton-street, Soho.*

THE following treatise has been composed for the instruction of such as are actually unacquainted with chemical science; and with that view I have followed such an arrangement of the subjects, as appeared best calculated to afford a clear and permanent knowledge of their relations and consequences.

As the proofs of chemistry are grounded upon an appeal to the senses, I have in the first place described some experiments, which are easy to be performed, and particularly adapted to exhibit the general nature of chemical action.

But mere facts do not constitute a science. The reasoning faculty must be exerted to dispose them in the order of cause and effect; first by the method called analysis, and afterwards in that of synthesis: which last may be considered as including those tentative processes of the mind called hypotheses, which in natural science are rendered legitimate by experiment.

To announce those generalities which have been deduced from the analytical labours of former philosophers, and constitute the theory of the science; to exhibit the conditions of the mutual actions of bodies; and to place the student upon an eminence whence he may contemplate the phenomena with advantage, and in many cases foretel events with certainty; require a display of the nature of chemical attraction, or affinity, and of heat. I have distinctly stated the laws of affinity in the synthetical form, and have then proceeded to illustrate those laws, by a series of experiments sufficiently striking, to interest the mind and fix the doctrine in the memory. The same method is adopted with regard to heat and light; which, together with attraction and repulsion, constitute the causes of every chemical change.

These positions and their illustrative proofs are immediately followed by the classification of the simple or undecompounded bodies, with their attributes, affections, or habitudes; which latter are proved experimentally.

The gases and the theory of their formation are next considered; their characteristic properties are detailed; the processes for obtaining them described; and a variety of the most appropriate experiments explained, by applying the general doctrines to each particular fact. Among these important first lines of chemistry, the formation of water; the production of various acids; the nature of the air we breathe; eudiometry; combustion; and many phenomena of the utmost magnitude

and value present themselves, and are elucidated by experiments.

The metals, alkalies, earths, &c. next succeed, and are treated in the same manner by direct reference to the facts they afford during chemical examination. The natural history of each, and their obvious physical and chemical properties, are first stated; then follow the means of obtaining them; and lastly, their physico-chemical properties are shown, by a series of experiments. A similar method pervades the whole of the work.

I have endeavoured experimentally to unfold all the fundamental truths of the science. I have proceeded from first notions step by step; from generals to particulars; from premises to conclusions; deducing causes from their effects, and effects from their causes, in order to maintain a systematic connection between the several parts of the whole, and to recal to the memory all the changes which bodies are susceptible of in their mutual actions.

I am persuaded this cannot be better done than by determining their properties by experiments under different circumstances. Hence the same facts are exhibited under various forms and relations, in order to oblige the mind to re-consider the same phenomena in different lights.

It is perhaps needless to state, that I have availed myself of all the authors who have cultivated and enriched

this science. In many instances I found perspicuity of style and precision of detail, on which I could not hope to make improvements; and in such cases I have not scrupled to transcribe whatever answered my purpose. But I have faithfully quoted my authorities, and rendered honour to whom honour is due.

They who are familiar with the science will nevertheless observe that I have done more than borrow from others. I have corrected errors which are found even in the works of modern authors of eminence; particularly in respect to the practical part of many processes. I have facilitated many operations; I have advanced a variety of new experiments, and pointed out such particulars in the performance of others as I have found in the course of my profession to be superior to those in general use.

The directions for performing chemical experiments, and the explanations in general, may be considered by some readers as too minute: but I am fully convinced that chemistry cannot be learned without actually applying to the operative part of the science. It is obvious that success must greatly depend on minute and clear instructions: this method of teaching cannot therefore be deemed trifling. I have indeed written for beginners; but accuracy and precision are so far from being faults, that they are more acceptable even to proficients, than that loose descriptive method which leaves the whole detail of quantities, order, and operation, to be supplied by the trials of the reader himself.

FREDRICK ACCUM.

London, 1803.

PREFACE

TO

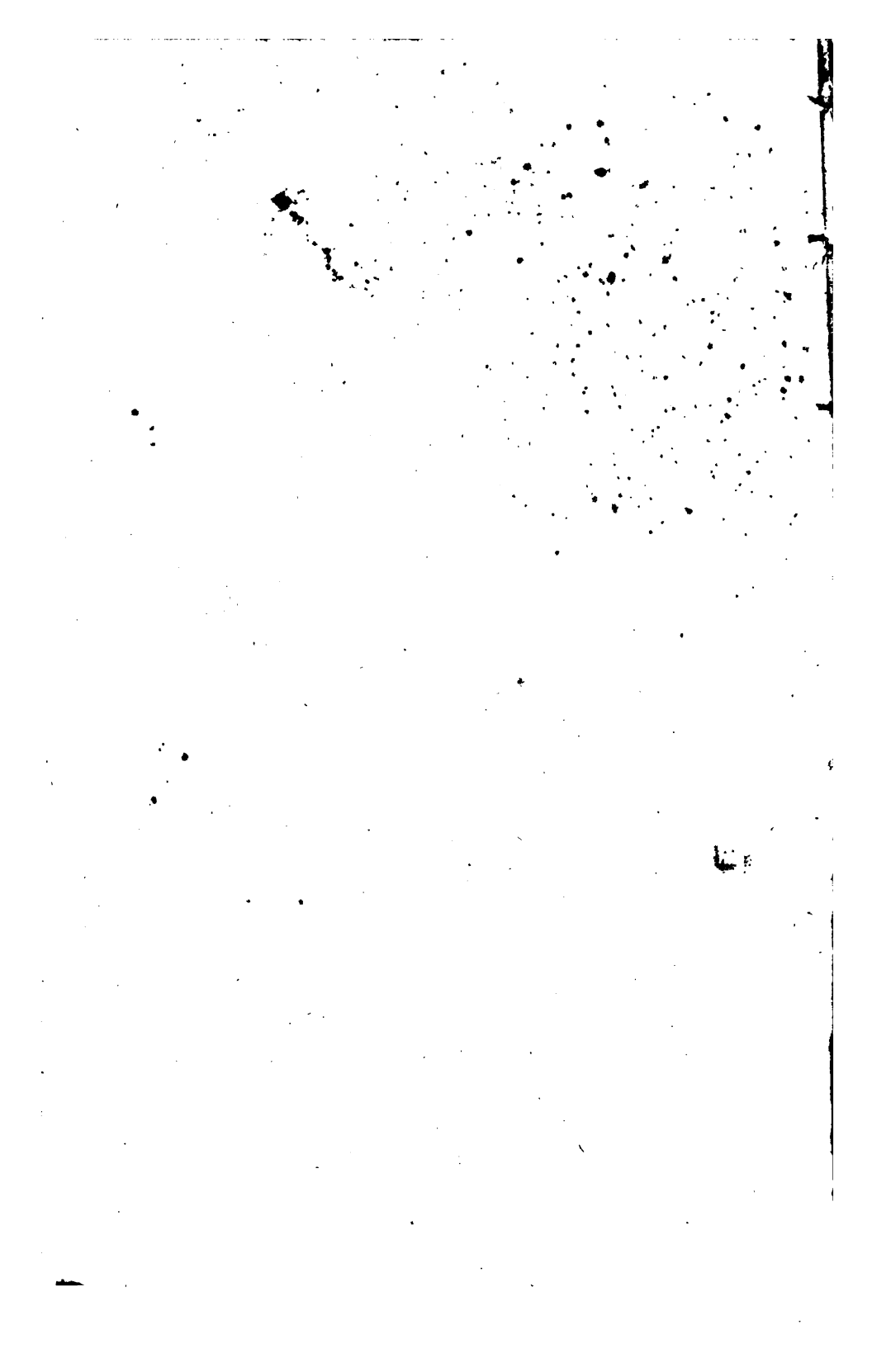
THE SECOND LONDON EDITION.

11, *Compton-street, Soho.*

I HAVE carefully revised the second edition of this work; the discoveries which have offered themselves in the field of chemical science are inserted, some new plates have been added exhibiting a variety of chemical instruments useful to the operative chemist, and no labour has been spared to render the present edition worthy of the distinguished approbation which this work has met with, amongst the chemical public.

FREDRICK ACCUM.

London, Jan. 1, 1807.



PREFACE

TO THE

SECOND AMERICAN EDITION.

IT is between six and seven years, since the last edition of Accum's Chemistry was published. The accumulation of chemical fact and the progress of chemical science, renders every elementary book on the subject imperfect after such an interval. Corrections and additions become necessary. It would have been better, if the author of this work had performed this duty himself, but as a new edition of the book is required, I have undertaken to do that which there is no present expectation of seeing done by the person most competent to the task.

Since the last edition in 1807, the discovery of the alkaline and earthy metalloids, the controversies on the important subjects of definite or indefinite combination in chemical affinity, and the nature of chlorine gas, have greatly interested the chemical world. The first volume of the elements of Chemical Philosophy by Sir Humphrey Davy has appeared, bearing the following characteristics, viz. That chemical attractions greatly depend on, if they be not the same with electrical—that the alkalies and alkaline earths are metallic oxyds—that all chemical combination takes place in multiple proportion—that chlorine is a substance sui generis, and like oxygen a supporter of combustion: positions that as yet may require hesitation and further examination; but they are of too extensive application to be neglected.

On all these subjects I have endeavoured to give a condensed summary of the doctrine or the controversy. I

have added also, my own views of the elementary properties of matter—of the nature of heat, light and combustion—and I have endeavoured to add such facts to Accum's collection as seemed to me likely to improve it as an elementary book.

The compilations of Murray and Thompson are too voluminous and expensive for an elementary treatise: the last (6th) edition of Henry, is a very good book and free from the objections to Murray and Thompson. But upon the whole, it seems to me that Accum's method of treating the subjects of chemistry, is more satisfactory to students than any other of the elementary treatises that have appeared: and it has the advantage of being neither too voluminous for a course, nor so brief as to be obscure.

When Mr. Accum thinks fit to publish a new edition, he will probably new model his work, and incorporate all the additions he thinks fit to make, in the body of the work. I cannot take this liberty, and therefore it must appear with patch work additions, which, however necessary to a distinct view of the modern state of the science, can only be justified by that necessity. I hope the notes I have added, will add to the utility at least of the work, and nothing further can be expected. I have endeavoured to make them useful; and so to compose them, as to lead the student to reflection and combination on the facts of the science: whether successfully or not, the public must decide.

THOMAS COOPER.

Carlisle, October, 1813.

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A SYSTEM

OF

THEORETICAL AND PRACTICAL

CHEMISTRY.

PART I.

SECT. I.

DEFINITION OF CHEMISTRY.

CHEMISTRY is that department of physical science the object of which is to investigate and account for the intimate changes produced in all bodies in nature by the mutual action of their parts upon each other; by means of which their physical properties are altered, and their individuality destroyed.

METHOD OF PERFORMING CHEMICAL OPERATIONS.

In examining the changes which take place in natural bodies, chemistry employs either simple *observation* or operative *experiment*. It either observes the processes which are incessantly taking place in the great laboratory of nature, or institutes, on purpose for this or that investigation, new processes of its own.

When we observe how water is converted into ice, and ice into water; how metallic substances lose their lustre in

the open air; we then acquire chemical knowledge by simple *observation.* When, again, we kindle a fire, that we may see its action upon some combustible or incombustible body; when we immerse a solid into a fluid, that we may learn whether the solid will be dissolved or not, in consequence of the immersion; in these and other such cases we investigate chemical truth by *experiments.*

Of the chemical knowledge acquired by simple observation every *man* possesses more or less; and a very considerable knowledge of the chemical changes of bodies may indeed be thus obtained. But mere unassisted observation is ever so inaccurate, so subject to accident, and so little capable of accomplishing any continuous and connected plan, that chemical inquiries almost always assume the form of *experiment.*

The artificial arrangement, or method which chemistry employs to favour the mutual action of bodies, consists in the proper application of those substances to each other which experience has taught us are best calculated to produce certain changes, that, in many cases, would otherwise be too minute to affect the senses individually.

Those operations themselves are called CHEMICAL PROCESSES, OPERATIONS, OR EXPERIMENTS.

GENERAL NATURE OF CHEMISTRY.

The processes of chemistry have been usually represented as either *analytical* or *synthetical.*

ANALYSIS, which is synonimous with decomposition, expresses the separation of the principles of a compound body. SYNTHESIS denotes the re-production of compound substances from simple bodies.

Analysis is divided into *simple* or *perfect*, and into *complex* or *imperfect*, analysis. It is called *simple* or perfect when, by means of synthesis, we can *re-produce* a body with the very substances which were the products of the analysis. It is complex or imperfect, when this cannot be effected. Simple analysis is the surest proof of the truth of chemical investigation: it is the most useful, and also the most rare, in all our artificial processes.

From this cursory account of the nature of the processes of chemistry, it becomes obvious that the whole art of the science consists in promoting the mutual actions of bodies

on each other, and carefully observing the phenomena that takes place. It must not be forgotten that these two methods do continually take place in the grand operations of nature, of which the chemist is only an imitator. The operations all depend on certain laws established between bodies, and require nothing more in order to their being rendered active than that the bodies should be placed into such situations as enable them to exercise their action. These important truths require to be maturely weighed and considered by the student who intends to embark in chemical pursuits.

Chemistry, therefore, consists in a detail of those facts which are founded on *experiments* and *observations*. Its basis is EXPERIENCE: from this, by regular conclusions, it deduces a THEORY, and connects a series of accurately established facts into a certain order, called a SYSTEM.

It follows from this that the evidence of chemical truth is, strictly speaking, only probable, not absolutely certain. This probability, however, is so much the greater as the experiments on which the observations are founded are more numerous, and have been more accurately performed. All possible exceptions, then, being made, we may venture to consider the results which offer themselves as true, till other facts are furnished, which by a more extensive and complete induction prove their fallacy.

It has been thus, by simple experiments and observation, that the science is become enriched with a store of facts. These facts have been gradually connected together, and arranged in such order as appeared most proper for exhibiting their reciprocal relation to each other; and at the same time for referring them to a smaller number of general heads, in order to consult them with the least difficulty, and to trace the *laws* that regulate them.

SECT. II.

SUBJECTS AND IMPORTANCE OF CHEMISTRY.

CHEMISTRY, in its connexion with the operations of nature and the existence of man, is highly worthy of an accurate examination. It unfolds the causes of many important phenomena; it enables us to reason concerning those properties of bodies which most immediately concern us, and to predict their alterations; and it developes to us sublime views of the order and harmony belonging to the different parts of our system.

This branch of science has been slowly formed, in consequence of minute observations made upon natural events, and of experiments in which natural agents have been placed in new relations: and though much has been done, much remains to be effected. The facts already ascertained are nevertheless sufficient to prove, that all the different known substances belonging to our globe are subjected to certain and invariable chemical laws, and that the most extensive and important chemical changes are continually taking place in the solid substance of the earth, the ocean, and in the atmosphere.

All material bodies are therefore the subjects of chemical research. The solid matters composing the terrestrial mass of the globe we inhabit; the aqueous fluids which penetrate its cavities, or float about its surface; the more subtile gazeous matter circumfused around it; the agencies of heat, light, and other imponderable substances expanded through space; are subjects for the chemical philosopher.

The events which chemistry holds out are equal to, and perhaps more important than, those which belong to mechanical philosophy. It extends itself into the province of active life. It is the nursing mother and guide of innumerable important arts. The arts of dyeing, bleaching, tanning, glass and porcelain-making, printing, the working of metals, &c. are purely chemical arts. They depend so much on that science, they are so combined

with its proper existence and its advancement, that all the steps which it makes in the knowledge of bodies, all the discoveries with which it is daily enriched, are so many new acquisitions for these arts; it perpetually improves them, adds to their processes, and creates new ones. *Agriculture* can only be rationally improved by calling in the assistance of the chemical philosopher; it is chemistry which explains the phenomena of vegetation, germination, the growth, the ripening, and the death of plants.

To the PUBLIC ECONOMIST chemistry presents a treasure of useful information. By means of this science alone can he expect to attack with success the destroying pestilence, so far as it is an object of human prevention, and to guard against other evils to which the state of the elements give rise.

To the DOMESTIC ECONOMIST this science abounds with pleasing and wholesome lessons. It enables him to make a proper choice of *meats* and *drinks*; it directs him to those measures with respect to *aliment*, *cookery*, *clothing*, and *respiration*, which have the best tendency to promote health, enjoyment, and cheapness of living; and it sets him on his guard against unseen evils, to which those who are ignorant of its laws are continually exposed.

The GARDENER, whose employments are more curious than those of the farmer, equally needs its assistance. The nature of the different manures necessary for the various kinds of vegetables, the influence of light, the different temperatures, the quantity of moisture, the preservation of seeds, roots, plants, &c. are all founded upon chemical principles.

Chemistry likewise directs the labours of the HUSBANDMAN. In the DAIRY, milk cannot be kept sweet and fresh, butter cannot be made, cheese cannot be prepared, without a skill founded wholly upon chemical principles.

The CULINARY ART, for preparing wholesome and nutritious food; and the method of preserving bacon, hams, and other animal and vegetable substances, is entirely chemical.

The whole PROCESS OF THE VINTAGE; the art of the brewer and distiller; the preparation of cyder, perry, home-made wines, &c. vinegar, &c. all depend upon chemical principles.

To the RURAL ECONOMIST this science furnishes principles and agents of inestimable value. It teaches him the food of *plants;* the choice and use of *manures;* and the best means of promoting the vigour, growth, productiveness, and preservation, of the various vegetable tribes.

In MEDICINE and PHARMACY great benefits have been derived from the discoveries of chemical philosophers. To the PHYSICIAN this science is of the greatest value. He learns from it to compound his medicines, to disarm poisons of their force, to adjust remedies to diseases, and to adopt general means of preserving health.

The chemist begins his inquiries where those of the natural historian and those of the natural philosopher terminate. The first of these examines bodies, in order to arrange them into certain classes, genera, and species: the second investigates the general properties of objects, such as their density, elasticity, figure, &c. and calculates the relative forces of their mechanical actions.

The chemist, however, goes further:...he looks into the more intimate structure of substances; he separates their heterogeneous particles from each other; he resolves them further into their simple or elementary substances, and examines their nature and properties when in a detached or simple state. He thus learns their reciprocal relation to each other, and becomes enabled to re-combine them in proportions different from those in which they were united by nature, in order to form new and useful compounds, which nature herself does not produce.

But chemistry is not only valuable as an art which supplies many of our wants, our comforts, and luxuries: its objects are sublime and beautiful in another point of view ...it removes the veil from the fabric of nature, and makes us acquainted with all the phenomena which happen around us...it affords pleasure to the senses, and calls into action a laudable curiosity, which characterizes the minds of those who are of a scientific turn; exciting at the same time a spirit of rational inquiry, which is capable of producing the most beautiful and striking phenomena, well calculated to serve as an instructive and rational amusement.

SECT. III.

HISTORY OF CHEMISTRY.

FROM what has been already stated, it becomes obvious that chemistry may be considered both as a science and as an art :....as a science, it may be said to be of modern date ; but as an art, it must be coeval with the earliest exercise of the industry of man; for many operations now considered chemical certainly must owe their invention to the immediate wants of society. The method of kindling fires, the arts of baking bread, moulding clays and burning them into pottery, extracting metals from their ores, the methods of working them, and various other processes, were certainly known to the ANTEDILUVIANS. If we attempt to trace its birth as a science, we find it originating in fables and obscurity ; nor indeed could we derive any chemical advantage if it were possible to dispel the cloud by which it is enveloped.

Whether Tubal-Cain, who is stated to have been a worker in metals in the time of Abraham ; whether Noah, who made wine and bricks, and who preserved the requisite stores of provisions in the ark, during the deluge ; whether Moses, who burnt the golden calf of the Israelites; or whether Cleopatra, who is said to have dissolved a pearl ; understood chemistry, are questions, important perhaps to the antiquarian, but of little value to the chemist. It is more plausible to suppose that a science so much depending on the state of the arts, the civilization of man, and the experience of ages, could not possibly exist in such a remote time. But as it would be in some respect unpardonable for those who devote themselves to the study of chemistry to be utterly unacquainted with its history, we shall shortly notice the outlines of this history, and fix the dates of the progressive discoveries of our predecessors which led to the establishment of the science.

The Israelites acquired their information in Egypt. It was there that Moses learnt the properties of metals, the method of extracting oils, the preparation of odoriferous

gums and perfumes, the solution of gold, the dyeing of linen, the making of wine, vinegar, the art of gilding, and the fabrication of pottery, soap, &c.

The PHŒNICIANS were the first who applied themselves to the examination of the effect of different bodies upon each other, which may be called chemical. They invented the art of tinging garments with a purple coloured matter, produced by a species of shell-fish. They manufactured glass, with which they traded; artificial gems, perfumes, and odoriferous balsams. They also invented the art of preserving the fruits of various plants and vegetables.

In China, even in these remote ages, the inhabitants were acquainted with nitre, gun-powder, borax, alum, verdigrise, sulphur, mercurial-ointment, various pigments, dyes for linen and silk, and with the art of making paper. They also manufactured porcelain, and different other kinds of pottery; they made a variety of metallic compounds. The use of wax was known to them, and was very well applied.

From this account of the state of the arts we may be permitted to consider the Chinese, according to Guignes, as an Egyptain colony.

The CARTHAGINIANS, who were a colony of the Phœnicans, learnt their arts; but the priests in whose hands the learning was retained, handed them to their successors veiled in hieroglyphic mystery.

The GRECIANS derived their arts depending upon chemical principles from the Phœnicians. They practised all the inventions of their predecessors successfully.

It it natural that the obvious difference or changes of the bodies that surround us could not escape the notice of a people of so philosophical a turn of mind as the Grecians: hence both Aristotle and Empedocles taught the doctrine of the four supposed elements, air, earth, fire, and water.

The ROMANS, a people always at war and victorious, were not distinguished among the nations of the ancient world as discoverers in the arts, or inventors in science. After having conquered and subjugated almost all the civilized parts of the earth, they arduously cultivated the arts of their masters, the Grecians. They understood the art of making excellent wines and ardent spirit: they knew the application of manures: they prepared incombustible

cloth for wrapping up the dead bodies which were destined to be burnt, in order to preserve their ashes distinct from those of the funeral pile: they moulded clays, and converted them, by burning, into different kinds of pottery; they were also acquainted with almost all the metals, and the methods of coining them: they were skilled in the culinary art; their cooks invented delicious sauces, as luxuries for their table: and the remains of their aqueducts, and other works of architecture, evince the incomparable perfection of their cements.

But all the arts, the sciences, and literature of the Romans and Greeks, were destined to sink into oblivion. Hosts of barbarian conquerors descended upon them from the North; the energies of civilization withered at their touch, and its works were destroyed before them.

During all this epocha of war and desolation chemistry acquired only a few facts, without connection and without order.

Driven as it were from Europe, the arts obtained an asylum with the Arabians; who improved many, and applied them to medicine. The attachment of this nation to magic, and their inclination for the marvellous, soon increased the mysteries in which the arts were then already involved; and hence alchymy, or the art of transmuting base metals into gold, took its rise. This happened about the commencement of the fourth century.

As this delusive dream of the imagination held out a bait to avarice, it soon acquired a train of followers. Intoxicated with the idea of the boundless wealth that would reward success, the great object was the philosopher's stone, and the possibility of the discovery of an universal medicine, which should cure every disease, and give immortal health and life to embodied man. The research was pursued with an ardour which no disappointment could damp, and the *mania* spread from one country to another. In Egypt it attracted the attention of the government. Dioclesian, apprehensive that the dreams of the alchymists might be realized, ordered all their books to be burnt, in order that he might subdue them with more facility.

After this period the alchymists were strongly opposed by several able and learned men. They were considered as people who held intercourse with malevolent spirits.

Roger Bacon, the alchymist, who is supposed to be the inventor of gun-powder, was excommunicated by the pope, and imprisoned ten years, for supposed dealings with the devil; and Paracelsus was thought to have an evil spirit confined in the pommel of his sword. Indeed, many of the adherents of alchymy endeavoured to enforce the belief of charms and spells. Paracelsus, the most impetuous man, who in ostentation and lies surpassed all his predecessor alchymists, promised immortality in this world to his followers; but his premature death, which happened in 1541, exposed his vanity, and blasted all their hopes.

It would surpass our limits were we to give a circumstantial detail of the state of the chemical arts at that period. It will be readily conjectured, that, owing to the great numbers of experiments which were performed amongst the alchymists, many valuable discoveries must have been made unintentionally. The alchymists actually collected a rich store of important chemical facts; and if they did not succeed in drawing gold from their furnaces, they produced those materials on which the true doctrine of chemistry was afterwards erected.

If we were to fix the existence of chemistry in the arts which it elucidated, it is evident that this science would have preceded every other; that Egypt would have been its cradle; and that it had been cultivated for time immemorial in China.

Vinegar was the only acid then known: amongst the salts they treated only of sea-salt, ammoniac, verdigrise, alum, and soda; which latter was called nitre. They distinguished no earth but lime and clay. Sulphur and bitumen were the only inflammable matters employed. They worked seven ductile metals; the brittle metals were unknown. There were no real experiments made in chemistry; so that among the whole of these facts we perceive nothing more than the infancy of the art: there neither was nor could be any scientific system, *for as yet the science of chemistry did not exist.*

At the end of the seventeenth century chemistry began to assume a scientific form. The scattered chemical facts which the alchymists had discovered, were collected, arranged, and reduced to principles.

The first chemical writer that excites our notice is Becher. This man collected all the facts which were noticed before him, and pointed out many important objects to which the researches of chemists ought to be directed. The publication of his *Physica Subterranea*, in 1669, forms a very important æra in the history of chemistry. At that period chemistry escaped for ever from the trammels of alchymy, and became the rudiments of the science which we find at present. Becher distinguished himself so highly by his chemical knowledge as to cause the names of all former theorists to be forgotten, after having laid the foundation of the famous system of phlogiston. He died in the year 1682.

Soon after his death arose one of his pupils, whose name was Stahl. He simplified and improved the doctrine of his master so much that he made it entirely his own; and accordingly it has been known ever since by the name of the *Stahlean Theory*. (*See Appendix No.* Q) He was the first who had a clear notion of chemical union, and gives many instances of double elective attractions. His writings have done him immortal honour, and ranked him amongst the first characters of the age in which he lived. He died in the year 1704.

Ever since the death of these chemists chemistry has been cultivated with success. Men of eminence have appeared every where; discoveries have been multiplied which led to numerous important facts. The names of Margraaf, Scheele, Bergman, Baume, Rouelle, &c. will remain distinguished in the annals of chemical science.

The spirit of chemical inquiry which these philosophers had infused summoned on a sudden into action the faculties of the most learned men of Europe. Several of the invisible agents which form so important a part in the economy of nature, were discovered. Dr. Priestley discovered, in 1777, various aerial fluids, formerly totally unknown to chemists; Dr. Black traced the laws of latent heat, and discovered the carbonic acid. The science of electricity was as it were created, the thunder was taken from the clouds, and the properties of the atmosphere were examined with accuracy.

All these new discoveries embarrassed the votaries of the doctrine of Stahl; and the conclusions to which they led were of such a nature as to puzzle and to contradict

many of the laws of the science. It was requisite to take but one step further that the doctrine of phlogiston might be exploded for ever. This was left to Lavoisier.

Lavoisier, endowed by nature with the most happy genius for science, and favoured by his own princely fortune and the liberal bounty of the French government, instituted a series of ingenious and accurate experiments, the result of which proved to demonstration that the theory of phlogiston was founded in error. His experiments were repeated, under every diversity of circumstances, by all the philosophers of Europe: his reasonings and inferences were vigorously attacked by the defenders of the phlogistic theory; a kind of chemical war was thus kindled in the republic of letters, which was carried on with great animosity; and posterity will see with regret men of undoubted genius at times divesting themselves of the armour of truth and candour, and endeavouring to serve their party and stab their adverse fellow-labourers with darts steeped in the poison of calumny and falsehood. These things have passed away: the contest has been productive of good effects, which infinitely surpass the bad ones: it has occasioned an accumulation of facts, produced a rigid examination of theories and opinions, introduced accuracy in chemical experiments, and given that tone and vigour to the cultivators of chemistry which have brought to light the most sublime and unlooked for truths.

The principles of Lavoisier have triumphed, and are now taught in all the schools of Europe: his opponents have become his disciples; and thus he has erected the luminous and beautiful theory of chemistry which all the chemists of Europe have now adopted. What a pity that the sanguinary tyranny of Robespierre should not even have spared this man! who perished on the 7th of May, 1794, under the axe of the guillotine.

Thus chemistry is become an entirely new science. It is no longer confined to the laboratory of the arts: it has extended its flight to the sublimest heights of philosophy, and pursues paths formerly regarded as impenetrable mysteries. Placed for ever in the elevated rank it now holds, rich with all its new conquests, it is become the science most adapted to the sublime speculations of philosophy, the most useful in advancing all the operations of

the arts, and the most rational for scientific amusement. Exact in its process, sure in its results, varied in its operations, without limits in its applications and its views, severe and geometrical in its reasoning, there is scarcely any human occupation which it does not enlighten, and upon the perfection of which it may not have great influence. It bestows enjoyment to every class of individuals: and who would not be ambitious of becoming acquainted with a science which enlightens almost every species of human knowledge?

Amongst the number of philosophers who have since that time cultivated and enriched the new theory of chemistry with discoveries which will for ever give immortality to their names, we have to notice Aikin, Allen, Babington, Bancroft, Beddoes, Blagden, Cavendish, Chenevix, Chrichton, Cruikshank, Dalton, Davy, lord Dundonald, lord Dundas, Fordyce, Garnett, Hatchett, Henry, Higgins, Hope, Howard, Kirwan, bishop of Llandaff, Murray, Nicholson, Pearson, Pepys, Tenant, Tilloch, Thomson, Wedgwood, and Wollaston; Achard, Arago, Biot, Crell, Gilbert, Gren, Goetling, Humbold, Hermbstaedt, Klaproth, Lowitz, Richter, Scherer, Tromsdorf, Westrumb, Wiegleb; Berthollet, Chaptal, Fourcroy, Lagrange, Guiton, Van Mons, Proust, Sequin, Vauquelin, Gay Lusac, Thenard, &c. &c.

THEORIES OF GEOLOGY.

PART II.

SECT. I.

THE material universe presents itself to an enlarged human observation as an immense assemblage of systems within systems, each complete in itself, yet connected, by numberless relations, with all around it; a larger still including a less, till all nature is, in this last grand result, comprehended in—ONE WHOLE.

The laws of this vast universe can be studied by us only in its inferior subdivisions. We conceive of it as subdivided into planetary systems. Comets are the only agents of combination among these systems with which we have any tolerable acquaintance. It is from the consideration of the appearances of that particular system to which our earth belongs that all our science concerning the laws of material nature is derived. When we confine our views to the globe we inhabit, we discover a vast variety of substances which may well excite our curiosity and arrest our attention. We perceive our earth to be a solid globe, composed of an assemblage of substances considerably fixed, and not to be destroyed without a considerable force of impulse. We observe a large part of it covered with an ocean, and numberless streams of cold liquid matter tending with great activity to incessant motion.

Around this earth and water, to a great but unknown height, is circumfused an atmosphere of an impalpable gazeous fluid, intermingled with portions of every solid

or aqueous matter that by an extreme comminution is capable of suspension in this aerial fluid.

Different opinions have been formed concerning the question, in what manner our earth was brought into the present distribution of its parts.

An origination of this globe out of a chaos was the general belief of the ancients. Moses, in the beginning of the pentateuch, gives an account of a series of successive changes, which he represents as the first which took place, from the moment at which matter was made subject to the laws it now obeys to that æra at which it was finally fit for the residence and support of animals, and had living inhabitants, brute and human, placed upon it.

In modern times, different classes of speculatists have attemped to investigate the circumstances which must have attended the origin of it.

Divines have endeavoured to justify the account of Moses, by an appeal to the present laws of nature: but Burnet and others have been easily convicted of supposing primæval states of things utterly incompatible with these laws.

Chemists have conceived that the origin of the earth, in its present form, is from a general liquidity of its whole matter: others again have attributed it to the action of fire.

Astronomers have been persuaded that it was owing to the action of some comet, or to an altered arrangement of the planets.

Others have conceived the idea of a world perhaps without beginning, but by the action of internal fires, with volcanic orifices, continually lacerated, undermined, and subverted, with the constant rise of a new earth, the residue and product from those fires, by which the former was demolished.

Others, again have fancied a continual flitting of the ocean around the globe; by which that which was lately land becomes now the bottom of the sea, and that which is now covered by the sea is again to become land.

These fanciful opinions, to say nothing of the impious nature of some of them, have generally rather resembled philosophical dreams than the conceptions of waking and sober reason. Their authors, in forming them, have been too often guided by imagination more than judgment; and

have laboured rather to support a favourite hypothesis than to consult the voice of authentic history, or patiently to examine the materials and structure of the fabric which they undertook to describe. It may, however, not be improper to take a brief review of some of the more conspicuous among the great number which, at different periods and in different parts of the world, have been received by philosophers.

SECT. II.

THEORY OF BURNET.

THE first theory of geology which deserves to be noticed is that of the Rev. Dr. Thomas Burnet.* This celebrated theorist was a man of genius and taste; and his work, if it do not command the assent of the philosophic mind, will be found to display much learning, and a very vigorous imagination. According to Dr. Burnet the earth was first a fluid heterogeneous mass. The heaviest parts descended and formed a solid body. The waters took their station round this body, and all lighter fluids rose above the water. Thus, between the coat of air and that of water a coat of oily matter was interposed. But as the air was then full of impurities, and contained great quantities of earthy particles, these gradually subsided and rested upon the stratum of oil, and composed a crust of earth mixed with oleaginous matter. This crust was the first inhabitable part of the earth; and was level and uniform, without mountains, seas, or other inequalities. In this state it remained about sixteen centuries, when the heat of the sun, gradually drying the crust, produced, at first, superficial fissures or cracks; but, in process of time, these fissures became deeper, and increased so much, that at last they entirely penetrated the crust. Immediately the whole split in pieces, and fell into the abyss of waters which it had formerly surrounded. This wonderful event was the universal *Deluge*. These

* *Telluris Theoria Sacra.* This work was first published in 1680 in the Latin language. It was afterwards translated by the author, and published in two parts in 1683 and 1690.

masses of indurated earthy matter, in falling into the abyss, carried along with them vast quantities of air, by the force of which they dashed against each other, accumulated, and divided in so irregular a manner, that great cavities, filled with air, were left between them. The waters gradually opened passages into these cavities, and in proportion as the cavities were filled with water, parts of the crust began to discover themselves in the most elevated places. At last the waters appeared no where but in those extensive vallies which contained the ocean. Thus our ocean is a part of the ancient abyss; the rest of it remains in the internal cavities, with which the sea has still a communication. Islands and rocks are the small fragments, and continents the large masses, of the antediluvian crust: and as the rupture and fall of the mass were sudden and confused, the present surface of the earth is full of corresponding confusion and irregularity.*

SECT. III.

THEORY OF WOODWARD.

THIS "elegant romance" of Burnet was succeeded by the work of his countryman, Mr. Woodward, who, in 1695, published *Essays towards a Natural History of the Earth*, and terrestrial bodies.

Though he possessed much more knowledge of minerals than his predecessor, and on this account had greatly the advantage of him, he produced a work far less ingenious and interesting. He also proceeded on the supposition of the Mosaic history being true, and ascribed the present aspect of our globe to the influence of the general deluge. He supposed that all the substances of which the earth is composed were once in a state of solution; that this solution took place at the flood; that on the gradual retiring of the waters the various substances held in solution, or suspended in them, subsided in distinct strata, according to their specific gravities; and that these are arranged horizontally, one over the other, like the coats of an onion. As this theory was soon found

* Sullivan's View of Nature, vol. i. Letter 6.

to contradict some of the plainest and most unquestionable facts which geologists observed, it has had few admirers, and its refutation has been usually considered as obvious and easy.

SECT. IV.

THEORY OF WHISTON.

IN 1696 Mr. William Whiston, a man of uncommon acuteness, and of still greater learning, published a *New Theory of the Earth*, from its original to the consummation of all things. He supposed the earth, in the beginning, to be an uninhabitable *Comet*, subject to such alternate extremes of heat and cold, that its matter, being sometimes liquefied and sometimes frozen, was in the form of a *chaos*, or an abyss surrounded with utter darkness. This chaos was the atmosphere of the comet, composed of heterogeneous materials, having its centre occupied with a globular, hot, solid nucleus, of about two thousand leagues diameter. Such was the condition of the earth before the period described by Moses at the time of *creation*. The first day of the creation every material in this rude mass began to be arranged according to its specific gravity. The heavy fluids sank down, and left to the earthy, watery, and aerial substances, the superior regions. Round the solid nucleus is placed the heavy fluid, which descended first, and formed the great abyss, upon which the earth floats, as a cork upon quicksilver. The great abyss is formed of two concentric circles; the interior being the heavy fluid; and the superior, water; upon which last, the earth, or the crust we inhabit, is immediately formed. So that, according to this theorist, the globe is composed of a number of coats or shells, one within the other, of different materials, and of different densities. The air, the lightest substance of all, surrounds the outer coat; and the rays of the sun, making their way through the atmosphere, produced the light which Moses tells us first obeyed the divine command. The hills and vallies are formed by the mass of which they consist pressing with greater or

less weight upon the inner coat of the earth; those parts which are heaviest sinking lowest into the subjacent fluid, and making *vallies*, and those which are lightest rising higher and forming *mountains*.

Such Mr. Whiston supposed to be the state of the globe we inhabit before the *Deluge*. Owing to the superior heat, at that time, of the central parts, which have been ever since cooling, the earth was more fruitful and populous anterior to that event than since. The greater vigour of the genial principle was more friendly to animal and vegetable life. But as all the advantages of plenty and longevity which this circumstance produced were productive only of moral evil, it pleased God to testify his displeasure against sin, by bringing a flood upon a guilty world. The flood was produced, as this theorist supposed, in the following manner. A *Comet*, descending in the plane of the ecliptic to its perihelion, made a near approach to the earth. The approximation of so large a body raised such a strong tide, and produced such powerful commotion in the abyss concealed under the external crust, that the latter was broken, and the waters which had been before pent up, burst forth with great violence, and were the principal means of producing the deluge. In aid of this, he had recourse to another supposition, which was, that the comet, while it passed so near the earth as to produce these effects by the force of attraction, also involved our globe in its atmosphere and tail for a considerable time, and deposited vast quantities of vapours on its surface, which produced violent and long-continued rains; and, finally, that this vast body of waters was removed by a mighty wind, which dried up a large portion, and forced the rest into the abyss from which it had been drawn, leaving only enough to form the ocean and rivers which we now behold.

SECT. V.

THEORY OF HUTCHINSON.

AT an early period of the eighteenth century, the celebrated John Hutchinson formed a theory of the earth, which he professed to derive from Scripture.* He supposed, that, when the earth was first created, the terrestrial matter was entirely dissolved in the aqueous, forming a thick, muddy, chaotic mass; that the figure of this mass was spherical, and on the outside of this sphere lay a body of gross dark air; that within the sphere of earth and water was an immense cavity, called by Moses the *deep*; that this internal cavity was filled with air of a kind similar to that on the outside; that on the creation of light the internal air received elasticity sufficient to force its way through the external covering; that immediately on this, the water descended, filled up the void, and left the earth in a form similar to that which it bears at present; that when it pleased God to destroy mankind by a flood, he caused, by his own miraculous agency, such a pressure of the atmosphere on the surface of the earth, that a large portion of it was forced into the internal cavity which it had formerly occupied, and expelled the waters from it with great violence, spreading them over the surface; that the shell of the earth was by this means utterly dissolved, and reduced to its original state of fluidity; and that, after the divine purposes were answered by the deluge, the globe, by a process similar to that which at first took place, was restored to the form which it now bears.

* This theory was enlarged and commented upon by Mr. Catcot, a follower of Hutchinson, who, in 1768, published a volume on the subject.

SECT. VI.

THEORY OF MORO.

IN the year 1740 the abbe Moro, of Italy, published a theory of the earth, which he chiefly derived from the works of Ray, of the preceding century. He supposed that the surface of the earth, as we now behold it, and especially the mountainous parts, arose originally from the bottom of the ocean. At first, according to him, these mountains contained neither strata of shells nor any organized fossils; but by means of subterranean conflagrations, earthquakes, and volcanoes, these substances were thrown up in confused heaps, after which they successively subsided according to their different specific gravities, and thereby necessarily disposed themselves in different strata. He also maintained that these submarine eruptions, while they threw up huge and irregular masses of matter, also ingulfed marine plants and animals of every kind, which subsided in like manner, and thus formed new mountains and new beds of stones, sand, metals, and other minerals, intermingled with the remains of vegetable and animal bodies, all which remained under the sea till some new agitation threw them above its surface. He supposed that the waters by which the earth was originally overflown subsided by degrees, the dry land first appearing in places adjacent to that where the first man and animals were placed at the creation; that the land extended itself gradually, a considerable time elapsing before the waters had returned into their proper bed, during which time the shell-fish, multiplying in great abundance, were universally distributed by the waters of the sea; and that when the bottom of the sea was raised up by the earthquakes that accompanied the deluge, and formed the mountains, whole beds of such shells were thrown up, and distributed as we now behold them.

SECT. VII.

THEORY OF LE CAT.

ABOUT the year 1744 M. le Cat, a philosopher of France, proposed a theory of the earth differing from all which had preceded it.

According to him, in the beginning, the substance whence metals, stones, earths, and other mineral bodies were to be formed, was a soft mass, consisting of a kind of mud. The earth was a globe, or regular spheroid, and its surface was uniform and free from hills and vallies. The sun and moon were afterwards created. The fluid which covered the mud became agitated by the flux and reflux to which it was subjected by attraction, and the mud was variously and violently moved. This agitation increasing, part of the mud became exposed, and dried. Continents were thus formed. The materials of the earth being compact and solid, the sea continually excavated its bed; and from the continual retreat of it, and the excavation of the earth, this globe is doomed to be at last so perfectly undermined as to produce a confluence of the sea from hemisphere to hemisphere. The earth becoming thus hollow, and its shell being gradually extenuated, will at length fall to pieces: a new chaos will be formed, the fabric will be again revived, as at first; and a periodical dissolution and renovation take place. Le Cat professed to believe the sacred Scriptures, and discovered an anxious desire to show that his theory was consistent with them; but the best judges among his contemporaries, and since that period, have pronounced it equally inconsistent with the structure and phenomena of our globe, and with the Mosaic history.

SECT. VIII.

THEORY OF MAILLET.

ABOUT the year 1750 appeared the *Telliamed* of M. Maillet, a French writer of some note. He taught, that the earth was once wholly covered with water, which, by means of strong currents, raised in its bosom all those mountains which different countries bear on their surface; that this water has been ever since gradually diminishing, and will continue to diminish until it shall be quite absorbed; that our globe, being then set on fire, will become a sun, and have various planets revolving in its vortex, till its igneous particles being consumed, it will be extinguished; that then it will roll through the immensity of space, without any regular motion, till it is again covered with watery particles, collected from other planets, when it will fix in the vortex of a new sun, and again go through the same course of motions and changes, being supplied with fresh inhabitants, resembling those by which it is tenanted at present; that the earth has probably been undergoing revolutions of this kind from all eternity, and will continue to go through a succession of them without end. This atheistical and absurd theory, if it deserve the name, not more hostile to revelation than to all sound philosophy, seems to have gained but few adherents, and but little celebrity.

SECT. IX.

THEORY OF BUFFON.

AFTER M. Maillet, his countryman, the count de Buffon, formed a new theory of the earth, which has been much celebrated, and, notwithstanding its inconsistency with revelation, and the visionary absurdities

which it involves, has gained many advocates and admirers. According to this ingenious theorist, a comet falling into the body of the sun with great force, struck from its surface a large mass of liquid fire. The comet communicated to this fragment, thus driven off from the sun, a violent impulsive force, which it still retains. This fragment forms the globe we inhabit. It assumed its present figure when in a fluid state. As the heated mass gradually cooled, the vapours which surrounded it condensed, fell down in the form of water upon the surface, depositing at the same time a slimy substance, mixed with sulphur and salts, part of which was carried by the waters into the perpendicular fissures of the strata, and produced metals; the rest remaining on the surface, and giving rise to vegetable mould, with more or less of animal and vegetable particles. Thus the interior parts of the globe were originally composed of vitrified matter, and they continue so at present. Above these were placed those bodies which the fire had reduced to the smallest particles, as sands, which are only portions of glass, and above these pumice stones, and the dross of melted matter, which gave rise to different clays. The whole was covered with water to the depth of five or six hundred feet. This water deposited a stratum of mud, mixed with all those materials which are capable of being sublimed or exhaled by fire, and the air was formed of the most subtile vapours, which, from their levity, rose above the waters.

Such are the outlines of a theory bold and plausible, as might have been expected from the mind of its author, but unsubstantial and deceptive. Its manifest object is to exclude the agency of a Divine Architect, and to represent a world begun and perfected merely by the operation of natural undesigning causes. That it cannot be reconciled with the sacred history, will appear evident on the slightest inspection; and that it involves the grossest philosophical absurdities has been clearly shown by succeeding geologists.

SECT. X.

THEORY OF RASPE.

M. de Buffon's theory was warmly opposed, soon after its publication, by Raspe, a geologist of Germany.* He also opposed the theory of Moro before mentioned, though he considered it as approaching much nearer the truth than the ingenious fable of the French naturalist. He insisted, that the opinion of continents and mountains having been thrown up from the bottom of the ocean, solely by submarine conflagrations and volcanoes, was abundantly refuted by close observation. He contended, likewise, that in veins of sand, marble, chalk, and slate, there are found no indications of a burning soil, but rather of a sediment disposed by the agitation of the sea. Accordingly, he maintained, that the strata, of which the shell or surface of the earth is composed, were originally formed at the bottom of the sea, by the constant agitation of the waters, and the continual production of plants and shells; that the subterraneous explosions and earthquakes, breaking through the bottom of the sea, not only formed banks, hills, and submarine mountains, of its broken parts, but also frequently raised up such large portions of the bed of the ocean, with its incumbent strata, as to form islands and dry mountains. At some times, as he supposed, the presence of so large a body of water caused it to break through the cavities made by previous eruptions, and at other times the violence of the subterraneous explosions was so great as to remove mountains from one place to another; while the heat of the internal fires causing these explosions was so intense as to melt, calcine, or vitrify, all adjacent substances.

* *Specimen Historiæ Naturalis Globi Terraquei.—Autore* Rudolpho Erico Raspe. 8vo. Leipsic, 1763.

SECT. XI.

THEORY OF WORTHINGTON.

IN 1773, Dr. William Worthington published a theory,* in which great learning and piety, and a considerable share of ingenuity, are combined. He maintained that the earth, in its primitive state, was plain and uniform: and that all mountains, and every thing irregular and rugged in the surface of it, are the result of the curse pronounced on the ground after the fall; that the melancholy lapse of our first parents was immediately followed by earthquakes, and every species of convulsion, which produced these dreadful effects in the surface of our earth; that the antediluvian earth greatly abounded with water, much more than at present, and that the greatest quantity of it was collected about the poles; that at first the poles of the earth were erect, and at right angles with the plane of the equator; that the centre of the earth was then the centre of gravity; that the deluge was produced by the centre of gravity being removed twenty-three degrees and a half nearer to one of the poles, which led to a corresponding deviation of the poles from their former position, and thus threw the great body of water accumulated round them on those parts of the earth where little had existed before, and by these means drowned them. This event he supposed, increased the irregularity of the earth's surface, and produced many of those phenomena, which so plainly establish the reality of the general deluge.

* *Scripture Theory of the Earth*, 8vo. 1773.

SECT. XII.

THEORY OF WHITEHURST.

ANOTHER British theorist, of still more celebrated name, published a new system of geology in 1778. This was Mr. Whitehurst, a gentleman of respectable talents and information, and whose theory has attracted considerable attention.* Mr. Whitehurst supposes, that not only this globe, but the whole of the planetary system, was once in a state of fluidity, and that the earth acquired its oblate spheroidical form by revolving round its axis in that state. In this fluid state, the component parts of the earth were suspended in one general undivided mass, "without form and void." These parts were endued with a variety of principles or laws of elective attraction, though equally and universally governed by the same law of gravitation. They were heterogeneous; and by their attraction progressively formed a habitable world. As the component parts of the chaos successively separated, the sea universally prevailed over the earth; and this would have continued to be the case had it not been for the sun and moon, which were coeval with the earth, and by their attractive influence interfered with the regular subsiding of the solid matter, which was going on. As the separation of the solids and fluids increased, the former were moved from place to place, without regularity; and hence the sea became unequally deep. These inequalities daily becoming greater, in process of time dry land was formed, and divided the sea; islands gradually appeared, like sand-banks above the water, and at length became firm, dry and fit for the reception of the animal and vegetable kingdoms. He supposed that mountains and continents were not primary productions of nature, but of a very distant period from the creation; that they are the effects of subterranean fires and commo-

* *An Inquiry into the Original State and Formation of the Earth, &c.* by John Whitehurst, F. R. S. 1778.

tions, and were produced when the strata of the earth had acquired their greatest degree of firmness and cohesion, and when the testaceous matter had assumed a stony hardness. And, finally, that the *marine shells* found in various places, on and below the surface of the earth, were for the most part generated, lived and died, in the places in which they are found; that they were not brought from distant regions, as some have supposed; and consequently, that these beds of shells, &c. were originally the bottom of the ocean.

SECT. XIII.

THEORY OF DE LUC.

TWO or three years after the appearance of Mr. Whitehurst's publication, M. de Luc, of Geneva, dissatisfied with all the numerous theories which had been proposed, offered another, which has occupied considerable attention in the scientific world.* He supposes that the ocean once covered our continents; that the bottom of the old ocean was full of mountains, which neither the waters, nor any other cause known to us, formed, and which he therefore calls *primordial*. These mountains rose above the surface of the waters, and formed islands. These islands, and the ancient continents, were fruitful and well peopled; and the ancient sea had tides, currents, and tempests, as the present ocean. These powers acting upon the soft matters which are known to have formed the bottom of the ancient ocean, produced accumulations of calcareous substances, which, in process of time, became more or less mixed with marine bodies. The rivers, in the mean while carried from the land into the sea scattered remains of animal and vegetable productions; the sea itself washed them from its coasts into its bosom; and these materials, transported by currents, became a

* *Lettres Physiques et Morales sur l'Histoire de la Terre et de l'Homme*, &c. by J. A. de Luc, 8vo. 5 tom. 1780. This theory, as to its principal outlines, was first suggested by Mr. Edward King; but was afterwards much extended and improved by M. de Luc.

secondary soil upon its primordial bottom. Fires and elastic fluids, formed by fermentations, made various openings in the bottom of the ocean, whence proceeded torrents of liquid substances and lava; which gave rise to the volcanic mountains observable on the surface of our continents. The continents which existed in a state of population and fertility, while the sea covered those which we now inhabit, though they did not form a solid mass, but were, properly speaking, vaults, which covered immense caverns, maintained their elevation above the level of the ocean by the strength of their pillars; which being of primordial matter, were solid and stable: but the changes which the subterranean fires produced at the bottom of the ancient sea opened passages for its waters into the interior of the earth; the fermentation produced by this eruption shook the pillars of the primitive earth; which sinking into its caverns, the old continents disappeared, and their surface descending below the level of the waters, a general inundation ensued. This was the general deluge: the sea now covered all the globe, except the islands of its ancient bottom; which increased in number and magnitude, until the weight of the water added to that of the superior vaults, crushed the inferior ones, and deepened more and more the new bed of the ocean; so that, at last, by a motion rapid, but not violent, all the waters retired from their former bed, and left our continents dry. Secondary mountains, and other irregularities, were afterwards formed by volcanic commotions and maritime currents and convulsions.

This learned theorist professes a firm belief in revelation; and insists that all the principal lines in the Mosaic history are confirmed, and none of them contradicted, by the most attentive survey of the globe. It may well be questioned, however, whether some parts of his theory can be reconciled with the sacred records: and they are precisely those parts which it is most difficult to reconcile with reason and sound philosophy.

SECT. XIV.

THEORY OF MILNE.

NEXT to the theory of M. de Luc appears that of Mr. Milne; which, though less celebrated, is by no means unworthy of notice.* This gentleman declares himself a warm friend to revelation, and professes to have formed a system in strict conformity with the sacred history. In some respects he agrees with Mr. Whitehurst; in others he adopts the opinions of M. de Luc; while, with regard to a third class of his doctrines, he claims to be original: he supposes that the earth, immediately after the fall, and in consequence of the divine curse pronounced against it, underwent a total change, by means of the elementary fire lodged at that time near its centre; and that hence arose the irregularities which now appear in the earth's surface.

SECT. XV.

THEORY OF DR. HUTTON.

THE theory of Milne was followed by that of Dr. James Hutton, of Edinburgh, which has been much more distinguished, and excited incomparably more attention. Dr. Hutton thinks,† that all our rocks and strata have been formed by subsidence under the waters of a former ocean, from the decay of a former earth, carried down to the sea by land floods; that the strata at

* A Course of Physico-Theological Lectures on the State of the World, from the Creation to the Deluge, by Robert Milne, A. M. octavo, 1786.

† Theory of the Earth; or, an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land upon the Earth, by James Hutton, M. D. F. R. S. E. This Memoir is contained in the Transactions of the Royal Society of Edinburgh, vol. i.

the bottom of the ocean were brought into fusion by subterraneous fires, and consolidated by subsequent congelation; that these strata were forced up, and made to form islands and continents by similar agency; that the shells and other exuviæ of animals, gradually collected and incorporated with these strata, make about a fourth part of our solid ground; and that the foregoing operations, *viz.* the waste of old land, the formation of new under the ocean, and the elevation of the strata now forming there into future dry land, are a progressive work of nature, which always did, and always will go on, forming world after world in perpetual succession. Consequently, according to this theory, the continents which we now inhabit must, in process of time, be worn away and destroyed, and others be forced up to supply their place. The length of time to be allowed for this successive destruction and reproduction, Dr. Hutton supposes to be far greater than is generally imagined. His system, therefore, is to be arranged, of course, among those which are hostile to the sacred history; and the best judges have pronounced it equally hostile to the principles of probability, to the results of the ablest observations on the mineral kingdom, and to the dictates of rational philosophy. (*See Appendix No.* 2.)

It has been suggested, that this doctrine of the *igniform* origin of our globe appears to be drawn from the theory of M. Buffon, with the difference of perpetually renovating powers, having no determinate commencement, instead of a once slowly forming and now gradually decaying principle. Dr. Hutton, indeed, does not attribute the fusion of terrestrial substances to the state in which this planet issued from the sun, but to subterraneous fires and furnaces, coeval with it, and still existing undiminished.*

* Howard's *Thoughts on the Globe*, &c.

SECT. XVI.

THEORY OF WILLIAMS.

IN 1790 appeared a new theory of the earth, by Mr. John Williams, a mineralogist, of respectable character, which, though it has not acquired much celebrity, is entitled to a transient notice in the present sketch.*

Mr. Williams supposes, that the superficial parts of the earth were originally mixed with water into a fluid or chaotic mass. All the regular strata were formed by the flow of the tides successively spreading out the deposited matters on a large horizontal plane. The granites and other stones, which he does not consider as stratified, subsided when the water was in some degree of rest, as at the highest of the tides, or where local obstructions produced stagnation. When the whole surface was in a fluid state, the tides, necessarily rose to a prodigious height, several miles higher than the tops of any of our mountains. The mountains of granite, which are uniform throughout, must have subsided in one tide. The tides were highest, and had their resting places on the two opposite parts of the globe, which are now the continents; and their direction, on different parts of the globe, was such as we now find that of the strata to be. He maintained, further, that the interior body of the earth was formed in the same manner, prior to the superficial parts. From various causes, it was full of inequalities: it contained much water both in the composition of the not yet consolidated strata and in separate cavities; so that when the superficial strata were laid between the tides, and the ocean began to retreat into its present bed, the weight of these superincumbent strata forced out the water imprisoned below them: these strata themselves, as yet soft and flexible, were, in many cases, bent and broken: cracks were occasioned by their contraction in drying; which cracks

* *Natural History of the Mineral Kingdom*, &c. by John Williams, 2 vols. 8vo. 1790.

were increased by the inclination of the strata in different ways, and were widest at the top; and the whole solid matter diminishing in bulk, as it became dry, high tides still overflowed it, and poured extraneous stony matter into the fissures. On these principles he explains all the declivities, ruptures, interruptions, and irregularities, which we now behold. The larger grains and fragments found in the composition of our rocks, and all those bodies which are of a similar structure, and not crystallized, were once in distinct strata, though not now to be found in that state. This he considers as one of the many evidences which our earth every where affords of the general deluge. By the high tides and violent agitation of the diluvian waters, the primitive strata, which had never before felt any rain, were loosened, torn asunder, and ground down by attrition against each other, and all the superficial parts of the earth reduced again to a chaos. When the waters began to abate, the larger stony particles and fragments subsided first, and formed the compound rocks and beds of sand; and the finer and lighter sediment was spread, by the tides, into strata of different consistency.

SECT. XVII.

THEORY OF DELAMETHERIE.

THE next theory entitled to notice is that of M. Delamétherie, of France, which has been, of late, very fashionable in that country, and produced considerable discussion.* He supposes that the external crust of our globe was formed in the bosom of the waters, from which it emerged in a state not very different from its present appearance. The crust, after its formation, underwent a variety of small alterations, from local causes. The waters surpassed the highest mountains: in other words, they were at least three thousand toises above their present level. All mountains, vallies, and plains,

* *Theorie de la Terre*, 8vo. 5 tom. Paris, 1797. This large work embraces much extraneous matter. The fourth and fifth volumes contain the author's theory.

were formed by *crystallization* amidst the waters. The materials which formed them were truly dissolved; but as they would require much more water for solution than is now to be found, it is evident that most of the waters of the primitive seas have disappeared. He thinks, that these have chiefly retreated into the bowels of the earth: that cavities were formed there at the time of the crystallization of the globe, which were at first filled with elastic fluids; but the water afterwards finding its way into them, became lodged there: that some caverns have been formed by subterraneous fires, but that the most powerful cause of them has been the refrigeration of our globe; and that, though the surface of the earth has been brought to its present state by the action of water, it may, at the first moment of its formation, have undergone a very great degree of heat, as happens to a comet passing near the sun.

In the formation of this theory, M. Delametherie discovered considerable ingenuity and great learning. He can scarcely, however, be called an original writer: Voigt had held the doctrine of the aqueous *crystallization* of strata before him; and, indeed, the greater part of his system is made up of parts collected from different theorists. This is generally considered as one of those theories which are hostile to revelation.

SECT. XVIII.

THEORY OF HOWARD.

OF a very different character is the theory of Mr. Howard, who about the same time published his opinions on this subject.* This gentleman is a firm believer in revelation, and his theory is intended to be perfectly consistent with the sacred history.

He supposes that the elements of all material substances were originally in a confused mass, called the abyss, without motion or animation; and that the present

* *Thoughts on the structure of the Globe, and the scriptural History of the Earth, and of Mankind*, &c. by Philip Howard, Esq. 4to. London, 1797.

order of things was gradually, and at different intervals, drawn from it, by means of laws impressed by the power of the Creator. The earth, of which we now behold the ruins, was originally constructed with its poles perpendicular to the equator; the centre of gravity was the centre of the globe; and the year consisted of three hundred and sixty days. At that time, the irregularities of the earth's surface being less considerable, and the distribution of land and sea being more equal, the atmosphere was more temperate and salubrious, and, of course, the life of man was prolonged greatly beyond its present limits. The termination of this "golden age" might have been effected by the proximity of a *Comet* condensing the vapours of the atmosphere and attracting the subterraneous waters, which, bursting through the exterior surface, precipitated indiscriminate portions of the primitive earth into the cavities below. The more perfect consolidation of the globe in the southern hemisphere changed the centre of gravity, which produced a proportionate deviation from the plane of the equator. The ocean did not, at once, however, sink to its present level. The posterior accession of waters from seas hitherto inland may have crushed down other inferior vaults, and finally settled its lowest degradations. As the land became thus elevated above the bed of the ocean, the cold became more intense, the vicissitudes of climate were more severely felt, and the life of man suffered a proportionate abbreviation.

SECT. XIX.

THEORY OF BERTRAND.

MR. Howard was succeeded by M. P. Bertrand, of France, who next proposed a theory, much less philosophical, and in every respect unworthy of a sober mind.*

This theory though exhibited and defended with some talents, may be considered as the most wild, and as involving the most palpable opposition to every received

* *Nouveaux Principes de Geologie*, par P. Bertrand, &c. 8vo. Paris, 1798.

principle, that has yet been presented to the public. Indeed, its unreasonableness and extravagance are so great, that it seems to have attracted but little respectful attention among any class of philosophers.

SECT. XX.

THEORY OF KIRWAN.

THE last person to be mentioned, as having adventured in this ample field of speculation and inquiry, is Mr. Kirwan. This gentleman with that learning which has enabled him to prosecute his numerous investigations in so enlightened a manner, with that judgment and penetration which render his inquiries so valuable, and with that spirit of patient and accurate observation which is so indispensably necessary to a successful development of this subject, has framed a theory of the earth, which is perhaps the most rational and probable extant.*

Mr. Kirwan believes that the superficial parts of the globe were originally in a soft liquid state, proceeding from solution in water heated at least to 33°, and possibly much higher: that this menstruum held in solution all the different earths; the metallic, the semimetallic, the saline, and the inflammable substances: that in this fluid its solid contents coalesced and crystallized, according to the laws of elective attraction; that these were deposited in strata according to the predominant proportion of the ingredients: that by this crystallization of these immense masses a prodigious quantity of heat must have been generated, and increased by the decomposition of the water intercepted in the precipitated ferruginous particles, and by the disengagement of inflammable air, even to incandescence; the oxygen uniting with the inflammable air, and bursting into flame; that this stupendous conflagration must have rent and split to an unknown extent the solid basis on which the chaotic fluid rested: that from the heated chaotic fluid must have been extricated the *oxygen* and *azotic* airs, which gradually formed the

* *Geological Essays*, by Richard Kirwan, Esq. F. R. S. &c. 8vo. 1799

atmosphere: that from the union of oxygen with ignited carbon proceeded the *carbonic acid*, the absorption of which, as the chaotic fluid cooled occasioned the crystallization and deposition of *calcareous earth*. Mr. Kirwan also believes, that the immense masses thus crystallized and deposited formed the primitive *mountains*; that the formation of *plains* took place from the subsequent deposition of matters less disposed to crystallize in the intervals of distant mountains; that the level of the ocean gradually subsided, leaving large and elevated tracts of land uncovered; that the *creation of fishes* was subsequent to the emersion of the land; that after this retreat of the sea, the earth soon became covered with vegetables and peopled with animals, being in every respect fitted to receive them; that the gradual retreat of the waters continued until a few centuries before the general deluge; that this event was occasioned by a miraculous effusion of water both from the clouds and from the great abyss—the latter originating in and proceeding from the great southern ocean below the equator, and thence rushing on to the northern hemisphere, spreading over the arctic region, and descending again southward; that during this elemental conflict, the carbonaceous and bituminous matter ran into masses no longer suspensible in water, and formed *strata of coal*; and that other substances, by the combination or decomposition of their respective materials, formed various other kinds of mineral bodies, as *basaltic masses*, *calcedonies*, *spars*, &c.

That the *inequality of declivity* exhibited by the sides or flanks of mountains, in every part of the globe, had any regard to the *points of the compass*, seems to have been first remarked by the celebrated Swedish geologist, Tilas.*

He supposes that this fact is connected with the original structure of our globe; that it proves that mountains are not mere fortuitous eruptions (as some, within a few years past, have confidently advanced) and that it furnishes a powerful argument in favour of the Mosaic account of the creation, deluge, &c.†

But, although there has been in modern times (as appears from the foregoing pages) a wonderful variety of

* See *Memoirs of Stockholm* for 1760.

† See *Transactions of the Royal Irish Academy*, vol. vii.

fanciful productions, under the name of geological theories, we are by no means to imagine that nothing has been usefully done in this department of natural history. Amidst all the splendid rubbish with which it has been incumbered, some precious treasures have been brought to light. Amidst the speculations which have *darkened counsel*, large additions have been made to our knowledge of this important subject. These may be briefly summed up in the following particulars.

The *materials* for the formation of a correct and rational theory of the earth have been greatly augmented during the last age. Enlightened mineralogists, practical miners, and patient chemical experimenters, have been engaged, throughout the century, in making accurate observations; in visiting foreign countries; in exploring the bowels of the earth; in comparing the strata of every portion of the globe; in examining their form, direction, extension, and connexion; in analyzing their component parts; and in collecting a multitude of facts, which have all tended to throw light on the origin and history of our planet. By means of the useful discoveries which these inquiries have made, we are furnished with weapons for beating down false theories, and with information enabling us to pursue our investigations further, and with more advantage.

Difficulties have been lately removed which were once supposed, by some, to militate strongly against the *possibility* of a *general Deluge*. Early geologists, for want of accurate information, supposed that all the waters of the globe were not sufficient to cover the whole earth to such a depth as the sacred historian describes. It was asserted that the mean depth of the ocean, did not exceed a quarter of a mile, and that only half of the surface of the globe was covered by it. On these data Dr. Keil computed, that *twenty-eight* oceans would be requisite to cover the whole earth to the height of *four miles*, which he judged to be that of the highest mountains; a quantity, which, at that time, was utterly denied to exist. But further progress in mathematical and physical knowledge has since shown, that the different seas and oceans contain at least *forty-eight* times as much water as they were supposed to do, and much more than enough for the extent ascribed to the deluge in the sacred history.*

* Kirwan's Geological Essays, pp. 66, 67.

While difficulties which were supposed to render the deluge *impossible* have been removed by the investigations of modern philosophers, many facts have been, at the same time, brought to light, showing the *probability*, and even *certainty*, of that mighty inundation. In every valley and mountain, support for revelation has been found. (*See Appendix No.* 3.) *Marine shells* have been discovered in situations so elevated, and under circumstances so remarkable, as to prove that they were left there by a flood extending over the whole globe; and what confirms this conclusion is, that shells peculiar to different shores and climates very distant from each other have been found in promiscuous heaps, plainly showing that they could have been brought together only by an extensive inundation. The bones of *elephants* and of *rhinoceroses* have been found, in a multitude of instances, far distant from the regions in which they are found to live, and where, from the nature of the climate, they could never exist in the living state: and between the climates which they might have inhabited, and the places, in which they are now found, too many mountains intervene to suppose them carried thither by any other means than a *general deluge*.* The most patient and accurate examinations of detached mineral substances, and of the strata of the globe, which late inquirers have made, afford every reason to believe that the earth was for a considerable time wholly overflowed with water. And, to crown all, as voyagers and travellers have explored new regions of the earth, they have found, every where, the indications of geological phenomena confirmed and supported by the notices of tradition. Accordingly, it is very remarkable that a great majority of modern theorists have embraced the *Neptunian* doctrines; and even such of them as rejected the Mosaic account of the deluge have been compelled to seek for other means of immerging the present continents in the ocean.

Finally, the researches of modern geologists have given abundant confirmation to the sacred history, not only with respect to the general *deluge*, but also with regard to the *age* of the earth.

* Kirwan's Geological Essays, p. 54, et seq.

NATURAL

HISTORY OF THE EARTH.

PART III.

SECT. I.

THE natural division of this globe of ours is into sea and land; about three-fourths of it being occupied by water, although probably no where to a depth comparatively very considerable. The remaining fourth consists of land, elevated more or less above the level of the sea, interspersed in some parts with small collections of water, at various heights, and, in a few instances, somewhat lower than the surface of the main ocean.

The internal constitution of the earth is little known. The deepest excavations that have been made by human art do not exceed 2400 feet, or less than half a mile; which is a very short distance indeed when compared with the diameter of the earth, which is about 7947 English miles: so that whatever lies below that depth is to us utterly unknown. The substances which have been extracted from those excavations are not in general of a nature different from those which in some particular places have been found immediately upon the surface. These substances are in general arranged in strata, variously inclined to the horizon, and of a thickness not very equal. Some indeed have supposed that they follow each other, in a certain order, almost throughout the globe; but this opinion appears to rest on slight foundations.

The mean density of the earth, deduced from the observations made by Dr. Maskelyne on the sides of Schehallien, an insulated mountain in Perthshire, is $4\frac{1}{2}$, rec-

koning water, as usual, the standard of comparison. Mr. Cavendish has lately assigned a greater quantity, or about $5\frac{1}{3}$, from a very elegant experiment on the principle of torsion, which Coulomb employed so successfully in a variety of delicate researches. Perhaps the true proportion would be found to lie between these limits. The observations of Dr. Maskelyne, however skilfully conducted by that eminent astronomer, were performed under the most unfavourable circumstances, in a foggy climate, and a rainy season. And Mr. Cavendish's experiment was not perhaps made on a scale sufficient to afford very great precision. Nor is it at all improbable, that the apparent force of attraction was in some degree augmented by a slight infusion of magnetic virtue; for the masses of lead which discovered their mutual appetency might yet contain a certain admixture of iron, in a state of such intimate combination as to resist the action of chemical solvents.

We are disposed to think that, instead of selecting a conical hill with a view to ascertain the deviation of the plumet, it would be more eligible to place the observer successively on the opposite sides of a narrow vale, bounded by two ranges of lofty mountains which run from east to west. Those stations would be very commodious for determining the altitude of a star, and their true distance could be found trigonometrically with the utmost exactness. The mountains themselves might be surveyed by considering them as composed of a number of parallel and vertical slices, formed by planes, in the direction of the meridian. The best scene that I am acquainted with for attempting these operations is in the Upper Valais, where the Rhone holds a westerly course; and the enormous Alps, in a double chain, having more than a mile of perpendicular height, approach at their lower flanks perhaps within two or three miles.

The surface of the earth, as well sea as land, is occupied by innumerable individuals, constituting an immense variety of distinct species of animated and inanimated beings, comprehended in three grand divisions of natural bodies, which have been emphatically called the three kingdom of nature, viz. the mineral, the vegetable, and the animal kingdom. This division is no doubt of great advantage in the methods of natural history; but

If we consider this branch of knowledge with a chemical eye, we must observe that this division has the inconvenience of not including a variety of bodies, which, by their mass, and by their vast influence, act a very important part in the operations of nature, viz. light, caloric, the air of the atmosphere. The above grand divisions may nevertheless be followed by the chemist with advantage.

The mineral kingdom consists of such substances as are composed of particles united, either without any regular form, or by accretion only.

Vegetables are all those organized bodies which derive their existence, by seeds or otherwise, from a parent stock. They grow by an enlargement of parts, have a certain period of life or existence, and are attached to a particular part of the soil, from which they derive the greatest part of their nourishment by superficial absorption only.

Animals are all those self-moving, organized bodies, of which the human being forms one species. They receive their food in an internal cavity, constituting a stomach.

Minerals have growth only, but not always; vegetables grow and live also; but animals have sensation, as well as life and increase of magnitude. (*See Appendix No.* 4.)

Mineralogy is so nearly allied to chemistry, that it cannot well be understood without a previous knowledge of that science. Vegetables present a spectacle very interesting by its variety, and by its elegance; but the philosophy of vegetation appears to be little diversified, and less understood. Some slight difference in the apparatus, by which the fruits and seeds are prepared for multiplying the individuals of each species, have formed the basis of the very excellent artificial system of Linnæus. But the class cryptogamia is separated by a more natural distinction, the preparation of the seed being less conspicuous, and in some cases scarcely intelligible, though in others an analogy with more perfect vegetables is perceptible; yet on the whole the class appears to form one of the connecting links between the three kingdoms. The herbs, palms, shrubs, and trees, which constitute the numerous genera of flowering vegetables, exhibit the greatest diversity in the forms and dispositions of the organs of fructification. And some of them indicate, upon particular irritation, a sensibility which seems to imitate the muscular motions of animals. In general, every ve-

getable may be considered as a congeries of vessels, in which, by some unknown means the aqueous fluids, imbibed by the roots, are subjected to peculiar chemical actions, and exposed in the leaves to the influence of the light and air, so as to be rendered fit for becoming constituent parts of the plant, or of the peculiar substances contained in its various parts.

A considerable portion of the bulk of all animals is also composed of tubular vessels, which originate in a heart, propelling through the arteries, which also co-operate with it, either a colourless transparent fluid, or a red blood, into the extremities of the veins, through which it again returns to the origin of its motion. Insects, and the vermes, or worms, have colourless juices, little warmer than the surrounding medium; but insects have legs furnished with joints, and worms at most have nothing but simple tentacula in the place of legs. Fishes have cold red blood, which is exposed to the influence of the air dissolved in water, by means of their gills. The amphibia receive the air into their lungs, but their blood is like that of fishes; and in both classes the heart has only two cavities, while that of animals with warm blood has four. Of these, the oviparous are birds, and are generally covered with feathers; the viviparous are either quadrupeds or cetaceous animals, and are furnished with organs for suckling their young.

The more perfect animals are informed of the qualities of external objects by the senses of touch, taste, smell, hearing, and vision. A few quadrupeds are incapable of seeing. Insects appear to want the organs of smell; but it is not impossible that their antennæ may answer the purpose of hearing: in a particular stage of their existence, most of their senses appear to be inactive. Many of the vermes are totally destitute of sight, and some of all the organs of sense.

The food, when received by the mouth, is subjected, in the more perfect animals, to mastication, and then enters the stomach; but in ruminating cattle it is first lodged in a peculiar receptacle, and more completely masticated at leisure. In the stomach, it undergoes digestion, and being mixed with the bile and other juices, becomes fit for the separation of the chyle by the absorbents of the intestines. The chyle is thrown into the veins, and passes

through the heart with the blood into the lungs, to be there mixed with it, and perhaps to be animalized; while the blood receives from the air a supply of oxygen, and emits some superfluous carbonic matter. Returning to the heart, the blood is distributed thence to every part of the system, supplying nourishment throughout, while the glands and arteries secrete from it such fluids as are become redundant, and such as are required for particular purposes. In these processes, heat is probably evolved. The muscles are furnished by the blood with a store of the unknown principle by which they are rendered capable of contracting, for locomotion or for other purposes, in obedience to the influence of the mind, transmitted by the nerves; and the brain and nervous system in general are sustained by means of the vascular circulation, in a fit state for transmitting the impressions on the senses to the immediate seat of thought and memory in the sensorium; and for conveying the dictates of the mind, and of the will, to the muscular parts of the whole frame.

In what manner these reciprocal impressions are transmitted by the nerves, has never yet been determined: but it has long been conjectured, that the medium of communication may bear a considerable analogy to the electrical agency; and late experiments appear to have added new weight to the opinion. Indeed nothing can be more fit to constitute a connecting link between material and immaterial beings, than some modification of a fluid which certainly differs very considerably in its essence from the common gross matter of the universe, and which perhaps pervades without interruption, the expanse of immeasurable space.

When the knowledge of these various subjects was not very extensive, all the known particulars could be easily arranged under the general title of natural philosophy; but the progress of civilization of man, and the unremitted attention which has been bestowed upon them, particularly within our own time, has increased the number of useful discoveries to such a degree, as to render the capacity of one man inadequate to the comprehension of the whole stock of knowledge. Hence to chemistry is allotted the explanation of those changes or events that are effected in the component parts of bodies by their mutual action upon each other, and which are not accompanied by sensible motion.

SIMPLE SUBSTANCES.

PART IV.

SECT. I.

NATURE OF SIMPLE BODIES.

IN every age there have been certain substances considered by the philosophers of the day as simple bodies or elements, of which every thing else has been supposed to be compounded. But what have been enumerated by the philosophers of one age as elements, have been afterwards proved by those of another to be compounds; and as the science of chemistry has been improved, we have discovered the means of analyzing or decomposing what was previously conceived to be simple. Thus water, and air, from time immemorial to a very late date, were allowed by all philosophers to be two of the elements of nature: modern chemists have, however, decomposed both fluids, and detected with accuracy the ingredients of which they are formed, and even the proportion in which these are combined.

For many ages past, earth, air, fire, and water, have been considered the four elements of which the globe we inhabit was formed. Chemistry now teaches, that there are many kinds of earths, and many kinds of air, perfectly distinct from each other. It teaches that fire is a simple substance; and that water is a compound.

This premised, simple bodies consist of particles which cannot be further separated into others of a more simple nature, or reproduced by artificial means. The true character of them is immutability of properties, unity, and similarity.

It does not follow from this that these bodies are absolutely simple; on the contrary, it is very possible that

they are compound. It cannot be doubted that, as the science advances towards perfection, many of them will be found so. Very probably a new set of simple bodies will offer itself, of which we are at present ignorant. These again may perhaps be decomposed, till at last, when the science has reached the highest degree of perfection, those really elementary substances will come into view, of which all bodies are ultimately composed. Whenever this shall happen, the list of simple substances will probably be reduced to a much smaller number than at present; till this however does take place, we are entitled to consider them as simple substances, according to the present state of our knowledge.

Their number amounts now to fifty, including those unconfinable agents called heat and light.

They may be conveniently arranged in the following order.

SECT. II.

CLASSIFICATION OF SIMPLE SUBSTANCES.

DIVISION I.

SIMPLE SUBSTANCES PRODUCIBLE BY ART.

2 IMPONDERABLE SUBSTANCES.

Light
Caloric.

PONDERABLE SUBSTANCES.

3 *Combustible bodies destitute of metallic properties.*

Sulphur
Phosphorus
Diamond.

28 *Combustible bodies, possessing metallic properties, called*

METALS.

Platina	Cobalt
Gold	Uranium
Silver	Titanium
Copper	Columbium
Iron	Chrome
Lead	Molybdena
Tin	Tungsten
Zinc	Arsenic
Mercury	Tantalium
Tellurium	Cerium
Antimony	Palladium
Bismuth	Rhodium
Manganese	Iridium
Nickel	Osmium.

INCOMBUSTIBLE BODIES.

6 EARTHS.

Silex
Alumine
Glucine
Zircon
Yttria
Magnesia.

5 ALKALIES.

Potash
Soda
Barytes
Strontia
Lime.

DIVISION II.

6 SUBSTANCES NOT YET PRODUCIBLE BY ART, BUT ANALOGICALLY CONSIDERED AS SIMPLE.

Oxygen
Nitrogen

Hydrogen
Muriatic radical
Fluoric radical
Boracic radical.

Such are the bodies which the corpuscular theory considers as simple, and to which chemical writers have given the appellation of RADICALS. Some can only be exhibited to our view in their simple state; others, on the contrary, have not yet been successfully exhibited experimentally, uninsulated. Their existence can nevertheless be inferred from the analogy of certain general and well-established facts. The impossibility of producing them arises no doubt from their great tendency to unite with other substances, and from the opportunity they meet with at every separation.

NATURE

OF

CHEMICAL ACTION.

PART V.

THE different actions which result from the proper application of the bodies enumerated before, when either in a simple state or when combined together, are founded on certain agencies inherent in all matter. This we take for granted, and consider as a fact; without pretending to explain *how* bodies came to be possessed of these agencies, or how they are capable of exerting them.

Philosophers therefore express the unknown causes which produce these changes, by the metaphors of ATTRACTION and REPULSION.

Before we attempt to give an explanation of these terms, we shall endeavour to exemplify what is understood by *chemical action in general.* We therefore flatter ourselves that the following simple facts intended for that purpose will not be deemed frivolous; our chief object being to advance in this place some palpable, positive, and negative proofs, which show, that whenever chemical action takes place, the properties of bodies become altered, and their individuality destroyed.

SECT. I.

INSTANCES OF CHEMICAL ACTION.

Experiment I.

LET a small portion of marble or chalk, reduced to powder, be diffused in a quantity of water, the marble presented to the water will fall to the bottom of the vessel and remain unaltered. On shaking up the whole, a white turbid mixture will be formed, but on letting it stand undisturbed, the marble will again fall to the bottom, and the supernatant fluid remain transparent and unaltered.

In this case no chemical action has taken place, for neither the properties of the marble nor the water are altered if examined chemically.

Experiment II.

If we let fall a like quantity of marble or chalk into another fluid, called an acid; for instance, into vinegar, or nitric, muriatic, or sulphuric acid; the effect then will be different: a violent action will take place the instant they come into contact, the marble will gradually disappear in these fluids and become more or less dissolved, and a transparent solution will be obtained.

In this case a chemical action has taken place between the bodies brought into the sphere of action, for the properties of both the substances can no longer be distinguished, their appearances are more or less altered, and their individuality destroyed.

Remark....Chemical action is reciprocal. It cannot be said that the acid acts on the marble, or the marble on the acid; convenience of expression has permitted the whole of the action to be attributed, without misconception, to one of the substances, when the effect of the action is to be examined instead of the action itself; hence we say, vinegar acts upon marble, water acts upon salt, &c.

It were to be wished that the action of different bodies upon each other could be referred to a few general laws,

so as to be enabled to foretel beforehand the changes which would result, in every possible circumstance. This would save us the trouble of learning in detail an immense number of insulated facts, which at present are necessary for the practice of the science.

Experiment III.

It is a well known fact, that if oil and water are added to each other they will not mix, because no sensible chemical action takes place between them under such circumstances; but if we add to the oil and water a sufficient quantity of another substance, called an alkali—for instance, potash or soda—the oil, the water, and the alkali, will then unite and form a saponaceous compound, which has a milky appearance, and renders water opaque.

A chemical action has then taken place between them; for the properties of the oil, the water, and the potash, are lost, and a compound possessing new properties has been formed.

Experiment IV.

If we put into a phial equal quantities of oil of turpentine, highly rectified alcohol, and a concentrated solution of carbonate of potash, and shake them together, no chemical change takes place; the different fluids will apparently mix, but on suffering them to stand undisturbed, they will separate again, and arrange themselves into distinct spherules. The heaviest fluid will sink with the greatest celerity, and they will place themselves over each other according to their specific gravities. *Three different fluids which do not mix, but constantly remain separate, will thus be contained in one phial.* In this instance, therefore, no chemical action takes place between the bodies presented to each other.

But if we bring the same substances into contact with others of a different nature, the case will be different, for violent chemical actions, will ensue under favourable circumstances; for instance,

Experiment V.

Accension of oil of turpentine, by the affusion of nitrous acid.

If we put into a tea-cup about one table-spoonful of oil of turpentine, and add to it double that quantity of

very concentrated nitrous acid, a violent action takes place, and fire and flame will be produced.

REMARK....As it is our duty to point out such experiments as may prove unsafe to those who never applied their hands to the practical part of chemistry, we must remark, that in performing this experiment care should be taken to avoid dangerous events; for the cup is sometimes shattered to pieces, and the mixture is thrown about in all directions to a considerable distance; it is therefore necessary to fasten the vessel containing the nitrous acid to the end of a long stick, in order that the operator may be at a distance when the accension takes place, which happens the instant the acid comes into contact with the oil.

EXPERIMENT VI.

Production of heat (sufficient to make water boil) by the mixture of sulphuric acid and alcohol or water.

If half an ale-glassful of sulphuric acid of commerce be hastily mingled with half that quantity of alcohol or water, the mixture instantly becomes so hot as to render the glass insupportable to the hands. A small quantity of water contained in a thin glass tube may be made to boil, when immersed in it for a few minutes only.

REMARK....Great caution is likewise necessary in making this experiment, lest the glass should crack from the sudden heat, and throw the mixture about, to the manifest danger of the operator. The safest method is to mix the two fluids gradually; by this means the heat is produced slowly; whereas if both fluids are at once mingled together, the heat is almost instantaneous, and rises considerably above that of boiling water.

EXPERIMENT VII.

Production of Sulphate of Potash.

If a concentrated solution, of carbonate of potash, be mingled with sulphuric acid, the two fluids unite, a very brisk effervescence takes place, and a solid mass of salt (sulphate of potash) will be produced.

These experiments, which shall be more fully considered hereafter, are merely advanced to prove that the

individuality of different substances becomes destroyed, that is to say, that a chemical action takes place when they are presented to each other under such circumstances as experience has taught us are necessary to produce such effects. The conditions, or artificial arrangements requisite for that purpose, resolve themselves into the general operations of chemistry.

ATTRACTION.

PART VI.

THE terms attraction and repulsion, in the language of modern philosophers, are employed merely as the expression of the general facts, that the masses or particles of matter have a tendency to approach to, or to recede from, one another, and to unite to, or repel, each other, under certain circumstances. Hence the following

AXIOM OF ATTRACTION.

All bodies whatever have a tendency or power to attract each other more or less; they search as it were, and make efforts, when left to themselves, to approach one another in order to unite, or to come into apparent contact. This energy is called the POWER OF ATTRACTION.

This attraction is mutual; it extends to indefinite distances. All bodies whatever, as well as their component elementary particles, are endued with it. It is not annihilated, at how great a distance soever we suppose them to be placed from each other; neither does it disappear, though they be arranged ever so near each other.

The nature of this reciprocal attraction, or at least the cause which produces it, is altogether unknown to us. Whether it be inherent in all matter, or whether it be the consequence of some other agent, are questions beyond the reach of human understanding; because we have no means of deciding the point, we are absolutely unable to judge of the simplicity of Nature. We have but a few imperfect glimpses here and there; and from the few points which we see and understand, we are not able

to form plausible conjectures concerning the whole machinery by which her operations are carried on. Superior beings perhaps smile at our theories, as we smile on the reasoning of a child; and were the veil with which her operations are covered suddenly withdrawn, we ourselves in all probability would be equally astonished and confounded at the wide difference between our theories and the real power by which the machinery of the universe is governed.

SECT. I.

PROOFS OF THE ENERGY OF ATTRACTION.

THAT the power of attraction really exists is obvious from the slightest view of the phenomena of nature. It is proved with mathematical certainty that the celestial bodies, which constitute the solar system, are urged towards each other by a force which preserves them in their orbits. It is further proved beyond any doubt, that this planetary attraction is possessed not only by the heavenly bodies as wholes, but that it also extends to the smaller particles of which they are formed, as may be evinced by means of the following experiments:

Experiment I.

If we place two or more globules of mercury on a dry glass or earthen plate, and push them gently towards each other, the globules will attract each other, and form one mass or sphere, greater in bulk, but precisely the same in nature.

Experiment II.

If a plate of clean glass, perfectly dry, be laid on a large globule of mercury, the globule, notwithstanding the pressure applied to it, continues to preserve its spherical form; if we gradually charge the plate with weights carefully, the globule will be depressed and become thinner and thinner; but if we again remove the weights from the

plate, the mercury will instantly recover its globular figure, and push up the glass before it.

In both these experiments we see that there exists an attraction between the particles of mercury; in the first, the globules which are in contact with the plate of glass leave this substance completely, they attract each other, and form a sphere greater in bulk. A mere inert fluid would in any case retain the figure it once possessed. It could not be endued with a globular form unless a real reciprocal attraction among its particles took place, which in the latter experiment is still more strking, for it there is not only superior to gravitation, but actually overcomes an external force.

Experiment III.

If a glass tube of a fine bore be immersed in water, contained in any vessel, the fluid will ascend to a certain height within the tube above its level, and its elevation in several tubes of different sizes will be reciprocally as the diameter of their bores.

This kind of attraction, which takes place as well in *vacuo* as in the open air, has been called capillary attraction. It is this attraction which causes water to rise in sponge, cloth, sugar, sand, &c. for all these substances may be considered as fine tubes in which the fluid ascends.

Remark...The ascension of fluids in glass tubes of a fine bore succeeds best when the inside of the tube has been previously moistened, which may conveniently be done by blowing through it with the mouth. And if the water be coloured with a little red or black ink its ascension will be more obvious, particularly if the tube be held against a sheet of white paper.

Experiment IV.

If two plates of glass, previously wetted, be made to meet on one side, and be kept open at the other, at a small distance, by the interposition of a shilling, or any other thin substance, and then immersed in water, the fluid will ascend between the two plates unequally. Its upper surface will form a curve, in which the heights of the several points above the surface of the fluid will be to one another reciprocally, as their perpendicular distance from the line

in which the plates meet. The ratio of this attraction is, therefore, as the squares of the increments with which the plates open.

Here, then, we have two other instances that an attraction prevails among the particles of bodies. For in both cases part of the fluid has left the contiguous mass, contrary to the laws of gravitation. It is drawn up, as it were, or attracted, by the tube or plate of glass.

Experiment V.

If we immerse a piece of tin, lead, bismuth, silver, or gold, in mercury, and draw it out again immediately, the mercury will attract the metal, and the latter will carry with it a portion of the former, which will stick to it so obstinately as to be inseparable by mere friction.

There exists, therefore, an attraction between the different metals brought in contact with each other.

Experiment VI.

If we let fall into water a lump of sugar or salt, the particles of the water attract those of the sugar with a greater force than the last particles attract each other; they are therefore gradually carried off by the water, that is to say, the sugar is gradually dissolved.

The particles of the solid thus dissolved, are each of them surrounded and combined with a certain number of the particles of the fluid; hence they must be arranged in the liquid in regular order, and at regular distances from each.

Experiment VII.

If a small stick be dipped in water, or any other fluid, and drawn out again, a drop will be found hanging at the end of it in a spherical form. The drop is spherical, because each particle of the fluid exerts an equal force in every direction, drawing other particles towards it on every side as far as its power extends.

Thus the very formation of drops obviously demonstrates that there must exist a cause which produces that effect. This cannot be gravity, for, agreeable to experience, that is rather an obstacle to the formation of drops; since, by the weight of the particles, large globules rest-

ing on solid bodies are flattened, and their regular spherical form prevented.

To explain this phenomenon there remains only the power of attraction, acting between the particles of the liquid body; for if it is supposed that the particles of a substance reciprocally attract each other with equal force, and their aptitude for being moved upon one another be great enough to overcome any impediment to their motion, it follows, by the principles of mechanics, that the equilibrium of the attractive forces can only take place when the mass has received a globular form.

Hence it is that all liquid bodies assume a spherical figure when suffered to fall through the air, or form drops.

Whether the attractions of gravitation, or magnetism, of electricity, and of cohesion, be or be not considered as essentially the same, is not our business to consider here circumstantially; there is difference enough between them to allow a very accurate examination of each. We merely consider attraction as an unknown power, by which all bodies are urged towards each other as an agent, which acts constantly and uniformly in all times and places, and which is always diminishing the distances between bodies. It is obvious that the distances of bodies are of two kinds, either sensible or insensible; consequently the changes produced by attraction must be either sensible or insensible. Hence the attraction of bodies naturally divides itself into two classes; those which act at sensible distances, and those which act at insensible distances. The attractions belonging to the first class must be as numerous as there are bodies situated at sensible distances; but it has been ascertained that they may be all reduced to three different heads, viz, gravitation, electricity, and magnetism. The first belongs to all matter, and therefore is universal: the other two are only partial, or confined to certain sets of bodies. The first extends to the greatest distances to which bodies are placed from each other: how far electricity extends, has not been ascertained. Magnetism extends, at least, as far as the semi-diameter of the earth. All bodies possess gravity; and it is supposed that the two other attractions are confined to certain subtile fluids which constitute a part of all those bodies which exhibit the attractions of electricity and magnetism. This may be so, but it has not and scarcely can be demonstrated.

SECT. II.

DIVISION OF ATTRACTION.

THOUGH we are unable to discover the cause of the mutual attraction, experience has proved to us that this agency follows certain conditions or laws; for similar phenomena always present themselves whenever the circumstances of experiment are the same.

Observation has taught us that the particles of bodies are of two kinds, either homogeneous or heterogeneous. By homogeneous particles, chemists understand particles composed of the same body; thus all particles of *sulphur*, &c. are homogeneous particles. By heterogeneous particles, chemists mean particles which compose different bodies; thus a particle of sulphur and a particle of mercury are heterogeneous particles.

In the early periods, when chemists perceived that the force here considered opposed their operations, being habituated to explain the effects they observed by certain relations, or analogies, which they supposed to exist between bodies, they gave different appellations, to express this agency. The first agency is still called by physical writers *corpuscular attraction*, or *attraction of aggregation; molecular attraction: attraction of cohesion*, or *the cohesive power*.

The latter is termed *chemical attraction*, *elective attraction*, *chemical affinity*, or *affinity of composition*. But before we consider this subject any further, we shall give an idea of what has been called *repulsion*.

REPULSION.

PART VII.

IT was mentioned before (page 54) that all matter possesses, besides attraction, another power which is in constant opposition to the former. This agency, which is equally powerful and equally obvious, acts an important part in the phenomena of nature, and is called *the power of repulsion.* It is not less interesting to the chemical philosopher, than the powers of attraction.

AXIOM OF REPULSION.

All bodies are endowed with a certain power, whose constant tendency is to oppose their approach towards each other, or to remove the particles of matter to a greater distance.

SECT. I.

PROOFS OF THE ENERGY OF REPULSION.

THAT there exists a force which opposes the approach of bodies towards each other is evident from numberless facts.

Newton has shown that when a convex lens is put upon a flat glass, it remains at a distance of the $\frac{1}{137}$ part of an inch, and a very considerable pressure is required to dimi-

nish this distance; nor does any force which can be applied bring them into actual mathematical contact; a force may indeed be applied sufficient to break the glasses into pieces, but it may be demonstrated that it does not diminish their distance much beyond the $\frac{1}{1000}$ part of an inch. There is, therefore, a repulsive force, which prevents the two glasses from touching each other.

There exists, therefore, a repulsion between bodies; this repulsion takes place while they are yet at a distance from each other; and it opposes their approach towards each other.

The cause, or the nature, of this force is equally inscrutable with that of attraction, but its existence is undoubted; it increases, so far as has been ascertained, inversely as the square of the distance, consequently at the point of contact it is infinite.

The following experiments will serve to prove the energy of repulsion more fully.

Experiment I.

We have seen (Experiment III. p. 56) that when a glass tube is immersed in water, the fluid is attracted by the glass and drawn up into the tube; but if we substitute mercury instead of water we shall find a different effect. If a glass tube of a large bore be immersed in this fluid it does not rise, but the surface of the mercury is considerably below the level of that which surrounds it.

In this case, therefore, a repulsion takes place between the glass and the mercury, which is even considerably greater than the attraction existing between the particles of the mercury, and hence the latter cannot rise in the tube, but is repelled, and becomes depressed.

Experiment II.

When we present the north pole of a magnet, A, to the same pole of another magnet, B, suspended on a pivot, and at liberty to move, the magnet B will recede as the other approaches; and by following it with A, at a proper distance, it may be made to turn round on its pivot with considerable velocity.

In this case there is evidently some agency which opposes the approach of the north poles of A and B, which

acts as an antagonist, and causes the moveable magnet to retire before the other. There is, therefore, a *repulsion* between the two magnets, a repulsion which increases with the power of the magnets; which may be made so great, that all the force of a strong man is insufficient to make the two north poles touch each other. The same repulsion is equally obvious in electrical bodies; for instance,

Experiment III.

If two small cork balls be suspended from a body with silk threads so as to touch one another, and if we charge the body in the usual manner with electricity, the two cork balls separate from each other, and stand at a distance proportional to the quantity of electricity with which the body is charged; the balls, of course, repel each other.

Experiment IV.

If we rub over the surface of a sheet of paper the fine dust of lycopodium or puff-ball, and then let water fall on it in small quantities, the water will instantly be repelled, and form itself into distinct drops which do not touch the lycopodium, but roll over it with uncommon rapidity. That the drops do not touch the lycopodium, but are actually kept at a distance above it, is obvious from the copious reflection of white light.

Experiment V.

If the surface of water contained in a basin be covered over with lycopodium, a solid substance deposited at the bottom of the fluid may be taken out of it with the hand without wetting it. In this case the repulsion is so powerful as to defend the hand completely from the contact of the fluid.

INFERENCES.

The various substances which compose the globe are therefore subject on the one hand to a general law which tends to unite them together, and on the other hand to another agent which tends to disunite, or to remove them to a greater distance. Hence it is impossible to produce

any change whatever in bodies without interrupting these respective agencies.

The great business of the chemist is to examine the changes arising from these agencies, and to trace the laws by which they are regulated. In doing this he investigates the operations of nature, and endeavours to point out their dependencies on one another. For that purpose he places different bodies in contact with each other under a diversity of circumstances, and observes the phenomena which accompany their action. He endeavours to trace the conditions under which they are produced, and examines the properties of the new compounds; thus making them subservient to the improvement of the arts, and rendering them the ministers of our necessities, comforts, and enjoyments. (*See Appendix No.* 5.)

CORPUSCULAR ATTRACTION.

OR,

ATTRACTION OF AGGREGATION.

PART VIII.

CORPUSCULAR attraction, or attraction of cohesion or aggregation, is that power by means of which the similar particles of bodies attract each other and become united into one mass, without changing, in the least, the chemical properties they possessed before their union. The bodies may be in a solid, fluid, or aeriform state.

Corpuscular attraction is different in different bodies. It is always in an inverse ratio to the power of repulsion, or the quantity of caloric interposed between the particles of the acting bodies.

It becomes obvious from this, that the agency of corpuscular attraction consists in a mere successive and constant accumulation of similar particles into one mass; and that it produces adherence of surface, or apparent contact in the ratio of the surfaces.

This force is inherent in all the particles of all bodies (caloric and light perhaps excepted) we never find the particles of bodies in a detached state, but constantly in masses of greater or smaller magnitude, made up of an indefinite number of particles united together by virtue of the force of cohesion.

SECT. I.

INSTANCES OF CORPUSCULAR ATTRACTION.

THE simplest case of the exertion of corpuscular attraction is that where two bodies, placed in mutual contact with each other, form a direct union, without changing their chemical properties.

EXPERIMENT I.

If different particles of sulphur be melted together, they form an uniform mass or whole, the particles of which are held together by virtue of the power of corpuscular attraction, but the properties of the body are not altered.

The same effect takes place when pieces of the same metal, or particles of resin, wax, &c. are united in a similar manner.

Innumerable other instances might be advanced, were not the subject obvious to every one.

MEASUREMENT OF CORPUSCULAR ATTRACTION.

The force of corpuscular attraction in solid bodies may be measured by the force or weight necessary to demolish it. Thus, if a rod of metal, glass, wood, &c. be suspended in a perpendicular direction, and weights be attached to its lower extremity, till the rod is broken by them, the weight attached to the rod just before it broke is the measure of the cohesive force of the rod.

It is also expressed by comparing it with other bodies: thus it is said that a ruby is softer than a diamond, but harder than the hardest steel, because with it the steel may be scratched, but not the diamond.

Various experiments have been instituted for the purpose of determining the force requisite to disunite solids from contiguous fluids, to disunite solids from contiguous solids, and to break or to disunite the continuity of a given solid. But the circumstances of temperature, purity

of the bodies, equality of size, surface, &c. render such experiments subject to a considerable uncertainty. (*See Appendix No.* 6.)

It has been found that wires of the following metals, drawn through the same hole, one tenth of an inch in diameter, and fastened with one end to a hook, whilst weights were suspended to the other extremity, could not be broken by any force less than the annexed weights.

Lead	29¼	pounds.
Tin	49¼	
Copper	299¼	
Brass	360	
Silver	370	
Iron	450	
Gold	500	

SECT. II.

GENERAL LAWS OF CORPUSCULAR ATTRACTION.

LAW I.... *The agency of corpuscular attraction acts only at insensible distances; its force* INCREASES *as the distance of the bodies presented to each other* DECREASES, *and as the surfaces of apparent contact are more numerous.*

EXPERIMENT I.

If from each of two leaden bullets a piece be cut off with a sharp knife, and if then the two bullets be pressed with their flat bright surfaces against each other (giving them a little twist) they will be found to adhere so firmly to each other, that sometimes the weight of fifty pounds will hardly be sufficient to separate them. When separated, a considerable degree of roughness will be found on their surfaces.

The adhesion of the two bullets is certainly not owing to the pressure of the surrounding medium; for in the first place the pressure of the atmosphere is by no means so great as to produce that degree of adhesion between such small surfaces; and, in the second place, the two bullets thus prepared are found to adhere as firmly in vacuo as they do in air.

EXPERIMENT II.

For similar reasons, two plates of glass wetted with a little water, to fill up their inequalities, when laid together, will cohere; and two pieces of marble or brass, having each a flat, smooth, and well polished surface, when moistened and slipped upon each other, with a gentle pressure, will unite, and a considerable force is required to separate them. But if the two substances placed together be not sufficiently smooth or polished, it will be in vain to try to cause them to adhere together; for this reason, that the particles touch each other only in a few points: whereas, on the contrary, the particles of the former flat and smooth surfaces touch each other in many points. It has been noticed, that a silk-worm's thread can be interposed, but not two.

EXPERIMENT III.

If two brass polished and perfectly flat surfaces, about three inches in diameter, be rubbed over with grease, and put together in a pretty hot state, they will, when cold, adhere to each other so firmly, as to require nearly five hundred pounds weight to disunite them.

It must be observed, however, that in these cases where something is interposed between the two surfaces, the adhesion seems to take place not between the surfaces of the two solids so much as between each of those surfaces and the interposed substance: for, in the first place, it seems strange that two surfaces should have a greater attraction to each other, when something is interposed, than otherwise; and, secondly, it has been found that the degree of cohesion differs, according as different substances are interposed between the very substances of the same solids.

It is on this account that carpenters, when they intend to glue pieces of wood together, plane the surfaces perfectly smooth, before they apply the glue; and that the surfaces of metals are scraped clean before they are soldered, &c.

Hence the corpuscular attraction always vanishes whenever the distance is measurable, and becomes exceedingly great whenever the distance is exceedingly diminished; but the particular rate which this power follows is still

unknown, as we have no method of measuring either the distance at which it acts or its relative intensity.

The force of gravity decreases inversely as the squares of the distance. But the attraction of cohesion decreases much faster: for instance, if a force of a thousand pounds weight be required to break a certain solid, and if then the broken parts be placed contiguous to each other, and so closely that the eye cannot discern the fracture, it will be found that they may be separated with the utmost facility.

LAW II....*Corpuscular attraction acts differently in different bodies; according to the degree of force with which it acts between the particles of matter, the bodies appear under different forms.*

1. It is on this account that rock-crystal, flint, diamond and various other precious stones, are extremely hard; for the corpuscular attraction unites the particles of these bodies with a great degree of force. Hence a considerable mechanical effort is necessary to disunite them.

2. In blocks of marble, chalk, lime-stone, &c. the particles are held together with a force considerably less. In these bodies it prevents all relative motion among the particles themselves, and hence the motion of one particle is followed by the motion of the whole mass; or if that is impossible, the cohesion is destroyed altogether, and the piece breaks.

3. The integrant parts of wax, tallow, suet, or lard, may be made to change their situations, with a less degree of force than the former.

Every genus of those aggregations comprehends a great number of species or degrees of solidity, softness, and liquidity.

In these substances the motion of one particle of the body is not necessarily followed by that of all the rest; neither does that motion destroy the cohesion, nor break them.

4. The particles of water, spirit, and ether, move or slide over each other very readily; hence their resistance is considerably less.

5. And lastly, vapours, the air of the atmosphere, and all the gases, yield to the slightest possible impulse.

LAW III....*Corpuscular attraction may be annihilated by every effort which tends to separate the particles of bodies.*

This law has, in truth, no relation to any chemical principle, but that of the destruction of aggregation. It is easy to imagine, that in order to produce this last effect nothing else is required to be done but to apply force greater than the agency of aggregation.

It need hardly be mentioned that all mechanical forces, such as grinding, cutting, filing, rasping, pounding, breaking, &c. are of this nature.

In all these cases, the power applied must be more than equal to the force of corpuscular attraction; and as it was stated before that the corpuscular attraction acts with different degrees of energy between the particles of different bodies, so different degrees of force are necessary to destroy that corpuscular attraction in different bodies.

The art of chemistry, in the different means it employs to demolish the aggregation of bodies, has really for its objects to cause these bodies to pass from the state of physical subjects (that is to say, subjects of which the mechanical philosophy can ascertain their properties) to that of chemical subjects, on which this science may be considered as no longer operating.

CHEMICAL AFFINITY,

OR

AFFINITY OF COMPOSITION.

PART IX.

SECT. I.

CHEMICAL AFFINITY.

AFFINITY of composition, or chemical affinity, is that power, by means of which the particles of bodies, whether simple or compound, attract each other so intimately as to produce an uniform whole, totally inseparable by mechanical efforts, and whose characteristic properties are often different, and sometimes contrary to those of its constituent parts.

It is obvious from this, that the particles of those bodies which are united by virtue of chemical affinity form not a mere aggregate, but an entirely new body, which can only be altered by the action of another chemical power.

In considering this kind of affinity, it will be necessary to state,

In what manner it takes place between the particles of different bodies;

In what proportion they are capable of combining;

Under what conditions;

With what degree of force they unite;

And what takes place when a variety of different substances are made to act upon each other at the same time, under certain circumstances and in different proportions.

Hence affinity of composition is of greater importance than corpuscular attraction, or affinity of aggregation, for it takes place in all the complex operations of chemistry. These topics will form the subject of the following sections.

SECT. II.

INSTANCES OF CHEMICAL AFFINITY.

To prove that chemical affinity acts differently from attraction of aggregation; that it takes place between the ultimate constituent parts of bodies; and that it produces substances possessing properties frequently very different, and sometimes contrary, to those of the constituent parts; the following experiments may serve.

Experiment I.

Formation of sulphuret of mercury.

Put into a crucible, placed in a coal fire, equal parts by weight of sulphur and mercury; stir the two substances together for a few minutes, and when the sulphur is melted pour the contents out on a marble slab, or piece of glass previously warmed and greased.

The substance obtained by this means is a *sulphuret of mercury*, in which the mercury and sulphur are united by virtue of chemical affinity: for the compound has neither the colour, the splendour, the inflammability, the volatility, nor the specific gravity, of either of its constituent parts; nor can the sulphur and mercury be separated by mechanical means: they are therefore chemically united.

Experiment II.

Two malleable and ductile metals form a brittle alloy.

If we melt together two very malleable and ductile metals—for instance, tin and iron—in equal quantities, the compound produced will have totally lost the properties

which its constituent parts possessed before their union; for the alloy formed will be a brittle metal, which may easily be broken with the blow of a hammer.

Experiment III.

Blue fluids become changed into red or green, green ones into crimson or purple, &c.

Put two or three tea-spoonfuls of an aqueous infusion of red cabbage, or syrup of violets, into a wine-glass of water; mix it well and put half the mixture into another glass. By adding a few drops of sulphuric acid to one of the glasses, and stirring it, the blue will be changed to a crimson; and by adding an alkali, for instance potash, to the other glass, the blue fluid will be changed into a green.

If we drop carefully down the sides of the glass into the green obtained in this experiment a few drops of sulphuric acid, crimson will be perceived at the bottom, purple in the middle, and green at the top. On adding a little alkali to the other glass, containing the crimson, these colours will appear in an inverted order.

Experiment IV.

Two inodorous bodies evolve a very pungent smelling gas.

(*Production of ammonia.*)

When equal parts of muriate of ammonia and slaked lime, both substances destitute of odour, are intimately blended in a stone mortar, a very pungent gas (ammonia) becomes evolved.

Experiment V.

Two odorous and pungent bodies produce a compound destitute of odour.

(*Formation of muriate of ammonia.*)

Water impregnated with ammonia and concentrated muriatic acid, both fluids of a strong odour, when mixed together in proper proportions, instantly lose their odour, and form a fluid void of smell (muriate of *ammonia.*)

Experiment VI.

Two fluid bodies produce a solid when mingled together.

(*Formation of sulphate of lime.*)

Into a saturated solution of muriate of lime let fall gradually concentrated sulphuric acid; a quantity of pungent vapour will become disengaged (muriatic acid gas) and from the two fluids will thus be produced an almost solid compound, called sulphate of lime.

Experiment VII.

Two solid bodies produce a fluid by mere mixture.

Let equal parts of fresh crystallized acetite of lead and acidulous sulphate of alumine and potash be rubbed together intimately in a stone mortar; the saline mixture will soon become soft, and lastly fluid.

A like effect is produced by treating in a similar manner equal parts of crystallized nitrate of ammonia and sulphate of soda.

A solid alloy of mercury and bismuth, and another composed of lead and mercury, on being triturated together instantly become fluid.

It is obvious from this, that when chemical combination takes place, the compound which is formed does not possess properties merely intermediate between those of its component parts, but has acquired others more or less new. This, however, does not hold good in all cases. There are various combinations, in which the properties of bodies are only slightly altered.

Sect. III.

GENERAL LAWS OF CHEMICAL AFFINITY.

Observation has shown that affinity of composition offers certain invariable phenomena, which being founded on a great number of facts, are regarded by chemists as laws, and may be reduced under the following heads:

LAW I.—*Chemical affinity can exert its actian between a number of bodies, simple or compound, and unite them chemically into one whole.*

LAW II.—*The efficacy of chemical affinity is in an inverse ratio to that of corpuscular attraction.*

LAW III.—*The agency of chemical affinity is influenced by temperature; its action is either accelerated, retarded, prevented, or rendered efficacious.*

LAW IV.—*Chemical affinity is accompanied by a change of temperature at the instant of its action.*

LAW V.—*The agency of chemical affinity existing between two or more bodies may lie dormant, until it is called into action by the interposition of another body which frequently exerts no energy upon any of them in a separate state.*

LAW VI.—*The ratio of the energy of chemical affinity acting between various bodies is different in different substances.*

LAW VII.—*The agency of chemical affinity is either limited or unlimited in certain bodies; in other words, chemical affinity is capable of uniting bodies in definite or in indefinite proportions.*

LAW VIII.—*The energy of the chemical affinity of different bodies is modified in proportion to the ponderable quantities of the bodies placed within the sphere of action.*

Such are the leading laws which regulate the affinity of composition; they may be demonstrated by means of the following experiments.

SECT. IV.

EXPERIMENTAL PROOFS OF THE LAWS OF CHEMICAL AFFINITY.

LAW I.—*Chemical affinity can exert its action between a number of bodies, simple or compound, and unite them chemically into one whole.*

PROOFS OF LAW I.

There are an infinite variety of compounds, consisting of three, four, five, or more simple substances in nature; and art can also effect combinations in which

there are many simple bodies chemically united into one whole.

It frequently happens that various separate bodies presented to each other in a fluid, unite and form a single mass, which possesses all the characters of an homogeneous compound, and which retains these characters till its composition has been altered by chemical means.

A considerable number of triple salts are known, which consist of three different substances; for instance, the common alum of commerce consists of sulphuric acid united to alumine and potash or soda. The salt formerly called microcosmic salt, or phosphate of soda and ammonia, consists of phosphoric acid united to soda and ammonia, &c. When the oxygenated muriate of mercury is precipitated by the precise quantity of carbonate of soda which is requisite to effect its decomposition, the precipitate obtained contains muriatic acid, carbonic acid, and oxyd of mercury in excess.

It is a well known fact, that two, three, or more metals may be fused together so as to produce compounds whose properties are widely different from those of the constituent parts.

Experiment I.

Fusible alloys which melt in boiling water.

Melt together, in an iron ladle or crucible, eight parts of bismuth, five of lead, and three of tin; the fusibility of the metals will thus be altered, for the alloy melts at 212° Fahr. A spoon, or any other utensil, formed of this compound, will therefore melt in water kept boiling.

If in a similar manner an alloy be made of lead, tin, bismuth, and mercury, their proportions being two, three, five, and one, the compound produced melts at a heat even less than that of boiling water.

A composition of lead, zinc, and bismuth, in equal parts, may be kept in fusion upon paper over a lamp.

Experiment II.

Put into a tea-cup one ounce of alcohol, and add to it ten grains of hyper-oxygenized muriate of potash. If to

this mixture a quarter of an ounce of concentrated sulphuric acid be added a violent action ensues, and the fluid bursts into flame.

Experiment III.

If we triturate together, in a warm mortar, three parts by weight of very dry nitrate of potash, two of carbonate of potash, and one of sulphur, a powder is obtained, of which a few grains, when laid on a knife and held over the candle, first fuses, and then explodes with a loud report. A drachm of it put into a shovel and held over the fire makes a noise as loud as a cannon, and indents the shovel as if it had received a violent blow. It is known by the name of *fulminating powder.*

Law II.—*The efficacy of chemical affinity is in an inverse ratio to that of corpuscular attraction.*

PROOFS OF LAW II.

It was mentioned before, that the cohesion of the particles of a body is owing to the mutual attraction existing between them. It is this force which must be overcome by the action of a substance which has a tendency to combine with those particles chemically. The affinity of composition therefore does not become *stronger* as the affinity of aggregation becomes *weaker*, it becomes only *more efficacious*; the absolute powers remain the same; the effect produced by that agency *increases*, because the resistance opposed to it *decreases*.

Remark....It is from this law that it was formerly inferred, that some, or at least one, of the bodies should be in a state of fluidity. This, however, is by no means necessary. It is in general true, that the weaker the attraction of aggregation is, the more easily the affinity of combination takes place, as may be evinced by means of the following experiments:

Experiment I.

Let any quantity of dry carbonate of soda and tartareous acid be mingled together, and put the mixture into a wine-glass; no chemical change will be produced: but if water be added, or either of the salts be previously dissolved, a violent effervescence ensues, and a chemical union is obtained.

The water added is of use merely to overcome the resistance which arises from the cohesion of the particles of the salts intended to be brought into the sphere of action, or to increase their mutual contact.

Experiment II.

If crystallized sulphate of alumine, or sulphate of soda, and acetite of lead are brought into contact with each other, the individuality of these bodies will not be destroyed, that is to say, no chemical change will take place: but if they be intimately rubbed together in a mortar, the two solids will act upon each other, and form a fluid.

It is obvious, therefore, that in order to facilitate chemical affinity, the attraction of aggregation must be broken; the bodies intended to be chemically united must not be presented to each other in their mass of contact, but mechanically divided, or reduced to the smallest moleculæ possible.

Hence liquids combine with more facility than solids, or even than a solid and a liquid; and in like manner vapours combine with rapidity and ease.

Law III.—*The agency of affinity of composition is influenced by temperature. Its action is either accelerated, retarded, prevented, or rendered efficacious.*

PROOFS OF LAW III.

Experiment I.

If we mingle equal parts of sulphur and carbonate of potash, and leave the mixture for any length of time, no

change will take place; but if we increase the temperature or heat the mixture, a union will be obtained.

Experiment II.

If we expose phosphorus in an open vessel to the action of the atmosphere, a chemical union will take place between the phosphorus and one of the constituent parts of the atmosphere, namely, the oxygen gas; the phosphorus will gradually (but very slowly) disappear, and become converted into a fluid, called phosphoric acid.

But if we heat the vessel containing the phosphorus, the latter will take fire, and become converted into a yellowish white substance, which in a short time is changed into an acid analogous to the former.

Experiment III.

If equal quantities of muriate of ammonia and carbonate of magnesia are mixed with six or eight parts of water, and suffered to stand for some time exposed to the ordinary temperature of the atmosphere, a mutual decomposition of the two salts will take place. For if the mixture and the fluid which passes are left to evaporate spontaneously, muriate of magnesia and carbonate of ammonia will be obtained.

On the contrary,

Experiment IV.

If equal quantities of muriate of magnesia and carbonate of ammonia be exposed to a temperature of 200° in about four parts of water, the products obtained are muriate of ammonia and carbonate of magnesia.

Experiment V.

If muriate of soda and sulphate of magnesia be mixed together in any proportion, and exposed to a temperature below *zero*, they decompose each other, and muriate of magnesia and sulphate of soda are formed; but no decomposition takes place at a temperature above 30°.

Muriate of soda, and acidulous sulphate of alumine and potash, exhibit precisely the same phenomena.

Experiment VI.

If ardent spirit and a solution of salt in water be mixed together, the compound formed is a real chemical union; but if we carefully heat the fluid, the caloric applied will be divided between the three ingredients, according to their respective affinities; the union will be broken, for the ardent spirits will first become volatilized, and the union of the salt and water remain unaltered. On increasing the temperature, the water will escape in the form of vapour, and the salt will be left behind.

There are numerous cases in which an increase of temperature is essentially necessary to determine bodies to unite. If mercury be exposed to oxygen gas, at the common temperature of the atmosphere, the corpuscular attraction subsisting between its particles is sufficient to prevent combination: but if the mercury be heated to a certain degree, the force which kept its particles united will become annihilated, and it then combines with the oxygen which is present.

Again, if the oxyd of mercury thus formed be exposed to a higher degree of temperature, the union is demolished, and the quicksilver re-appears in its metallic state.

Hence it is obvious that the action of caloric favours the union of the oxygen and mercury, in consequence of the diminution of the mutual affinity of the parts; but at length, by augmenting this difference, it again breaks the union, or renders the combination impossible.

That increased temperature augments the powers of chemical union the solutions of salt and water afford instances.

A larger quantity of salt is soluble in a given quantity of water at a high than at a low temperature, and this larger quantity of salt is again separated by cooling.

Law IV.—*Chemical affinity is accompanied by a change of temperature at the instant of its action.*

The truth of this principle will be perceived by applying experiment to theory.

PROOFS OF LAW IV.

Experiment I.

Production of heat, by the combination of dense acids, alkalies, &c. with water.

We have mentioned already (page 52) that when two parts of concentrated sulphuric acid and ardent spirit are mingled together, the mixture in a few minutes becomes so hot as to render the vessel insupportable to the hands.

If four parts of sulphuric acid of commerce and one part by weight of water be mixed together, each at the temperature of 50°, the mixture immediately acquires a temperature of about 300°.

All the dense acids, ammonia, and ardent spirit, when mixed with water, have the property of raising its temperature remarkably: and the same is the case when alkalies are introduced into concentrated acids. On the contrary, in many instances cold is produced.

Experiment II.

Production of extreme degrees of cold.

Take one ounce and a half of muriate of ammonia, and a like quantity of nitrate of potash; reduce each of these salts separately to powder, and blend them intimately together: having done this, mix them gradually in a glass basin, or other thin glass vessel, with four ounces of water. The result will be, that the cold produced sinks a thermometer immersed in it to 36° Fahr. A new addition of the same quantity of salts will cool it to 14°, which therefore will freeze water in a glass tube that is immersed in it, without the use of snow or ice. If the water employed in a first process be used to reduce other water and salts to the temperature of about 32°, and these be applied to the performance of a second experiment, the temperature may be lowered to 4° below 0°.

A number of experiments have lately been made to produce artificial cold by means of such freezing mixtures. The most complete set of this kind are those of Pepys, Lowitz, and Walker. They shall be noticed in the next part of this work.

LAW V.—*The agency of chemical affinity between two or more bodies may lie dormant, until it is called into action by the interposition of another body, which frequently exerts no energy upon them in a separate state.*

From this law originates what was formerly called disposing affinity, or that case in which two or more bodies are incapable of uniting, until the agency is called into action by the addition of a third body, which exerts no sensible affinity upon either of them.

This may be proved in the following manner.

PROOFS OF LAW V.

Water is a compound of hydrogen and oxygen; phosphorus is a simple body, according to our present state of knowledge. If these be presented to each other, no chemical union will take place; but if we add to them an alkali, and then apply heat, the water will become decomposed; that is to say, part of the phosphorus will unite to the oxygen of the water and form phosphoric acid, and the other part will be dissolved in the hydrogen gas and appear as phosphorated hydrogen.

Here the alkali acts as the substance requisite to favour the mutual action, or to give the disposing affinity.

If iron and water be brought into contact with each other, no perceptible change will be produced; but if a little sulphuric acid be added to the water and iron, a violent effervescence takes place, the water becomes decomposed, hydrogen gas will be evolved, and the iron become dissolved in the acid.

In this case the sulphuric acid is the condition necessary to accelerate the chemical action.

These experiments will be more fully considered hereafter.

LAW VI.—*The ratio of the energy of chemical affinity acting between various bodies is different in different substances.*

This is the most important law of chemical attraction. As beginners will find it rather difficult to understand what passes in this more complicated agency, we shall

shortly remark, that the combination which is effected between two or more bodies, by virtue of the affinity of composition, becomes broken whenever we present to the compound another body, which has an attraction to one of the constituent parts of the compound, superior to that attraction by which they were held together: the bodies, therefore, between which the strongest attraction prevails combine, and the rest are disengaged.

PROOFS OF LAW VI.

Experiment I.

If muriatic acid be poured either on pure barytes or on its carbonate, the barytes will be dissolved, and the compound will be muriate of barytes, which compound is held together by the force of affinity existing between the muriatic acid and the barytes. On letting fall into this solution a few drops of sulphuric acid, an immediate change of principles takes place; the whole quantity of the muriatic acid which was combined with the barytes becomes disengaged; and the sulphuric acid unites to the barytes with a force equal to their affinity, *minus* that of the muriatic acid.

Experiment II.

If pure silver be dissolved in nitric acid, the silver will remain united to the acid till another body is presented to it which has a greater force of attraction to one of the constituent parts of the compound: for instance, if mercury be added to this solution of silver, the mercury will be dissolved, and the silver become precipitated or disengaged. The supernatant fluid will then be a *solution of mercury in nitric acid.*

Experiment III.

If to the before-obtained solution of mercury in nitric acid a piece of sheet lead be presented, the lead will be dissolved, and the mercury become precipitated. The fluid will then be a *solution of lead in nitric acid.*

Experiment IV.

If in this solution of lead a thin slice of copper be suspended, the copper will be dissolved, and the lead will become disengaged. The fluid now is a *solution of copper in nitric acid.*

Experiment V.

If in this solution of copper a thin sheet of iron be kept immersed, the iron will be dissolved, and the copper become precipitated. The fluid now is a *solution of iron in nitric acid.*

Experiment VI.

If to this solution of iron a piece of zinc be presented, the zinc will be dissolved, and the iron become precipitated. The solution then consists of *zinc and nitric acid.*

Remarks....It appears nevertheless, from Berthollet's Treatise, as we shall see directly, that in almost all cases of elective affinity, there is not a total transfer of the base, but that a division is made between the two opposite attracting substances, in a compound ratio of the relative force of affinity and quantity of each; that, in many cases, the excess of quantity may supply the deficiency of force, and therefore that the *mass* must be carefully taken into consideration.

Law VII.—*The agency of chemical affinity is either limited or unlimited; in other words, chemical affinity is capable of uniting bodies in definite or in indefinite proportions.*

Experience has convinced us, that in all bodies there are certain precise limits of combinations beyond which their action cannot pass, namely, a *minimum* and a *maximum*; it remains still to be ascertained how bodies can combine within these limits.

If we attend to what is known at present, we are forced to acknowledge that this law comprehends several modifi-

cations, which may be arranged under the following classes.

1. Chemical affinity unites several bodies in any proportion whatsoever; their combination is therefore unlimited: for instance,

PROOFS OF LAW VII.

Experiment I.

If water and ardent spirit be mingled together in any quantity, a chemical combination ensues, for the compound obtained has always a specific gravity different from the mean specific gravity of the fluids combined. Its bulk is likewise not the arithmetical mean of the fluids in a separate state.

The same is the case when liquid acids and water, or acids and ardent spirit, are combined together.

2. Chemical affinity combines several bodies to a certain extent or *maximum* only.

To this class belong all those bodies which are capable of (what is called) saturation.

Experiment II.

If we take a quantity of any of the dense acids diluted with water—for instance sulphuric acid—and let fall into it a solution of an alkali—for example soda—by a little at a time, and examine the mixture after every addition of the alkali, we find for a considerable time it will exhibit the properties of an acid, it will have a sour taste, and convert vegetable blue colours into red; but if we continue to add greater quantities of soda, these acid properties will gradually diminish, and at last disappear altogether. At that point the combination is at an end, it has reached its *maximum* in this case; for if we continue to add more alkali, the mixture will gradually acquire alkaline properties; it will convert blue vegetables into green; it will have an urinous or alkaline taste, &c. These properties will become stronger the greater the quantity of the soda is which is added.

Experiment III.

Take muriatic acid, and let fall into it gradually carbonate of lime or magnesia: an effervescence will take place; for a chemical union ensues between the acid and the lime, or magnesia, and the carbonic acid, the other constituent part of these bodies, becomes disengaged. But if we continue the addition of the lime or magnesia until it produces no further effervescence, no chemical union will be obtained, the lime will fall to the bottom unaltered, for the combination is at its *maximum*.

It is on this account that water can only dissolve a certain quantity of salt; ardent spirit, a certain quantity of resin, &c.

The union of oxygen and hydrogen belongs likewise to this class.

3. Chemical affinity is capable of uniting different bodies in two, three, or more proportions; each of these combinations produces compounds possessing peculiar properties.

This peculiarity of combination is highly important.

It is owing to this circumstance that both nature and art produce substances of the same principles, only combined in different proportions, which possess peculiar properties widely different from each other.

Law VIII.—*The energy of the chemical affinity of different bodies is modified in proportion to the ponderable quantities of the substances placed within the sphere of action.*

It is obvious from this, that the denomination of elective affinity is erroneous; since it supposes the union of one entire substance with another in preference to a third. But this is not the case; a mere division of action takes place in instances of this kind; that is to say, the substances act according to the quantity existing within the sphere of activity. The excess of quantity is capable of compensating for the deficiency of the force of affinity. When, therefore, a compound body of two substances is acted on by a third, that part of a compound which is the subject of combination is divided between the two remaining, not only in proportion to their respective de-

grees of affinity, but also according to their ponderable quantities; so that by varying this in either, the effect produced will be varied.

Thus Berthollet has proved, that in all cases a large quantity of a body is capable of abstracting a portion of another from a small portion of a third, how weak soever the affinity between the first and second of these bodies may be, and how strong soever the affinity between the second and third. Thus potash is capable of abstracting part of the acid from oxalate of lime, phosphate of lime, and carbonate of lime. Soda and lime decompose partially sulphate of potash. Nitric acid subtracts part of the base from oxalate of lime, &c.

The following experiment, advanced by Berthollet, will prove this more clearly.

PROOFS OF LAW VIII.

Experiment I.

If equal parts by weight of sulphate of barytes and potash be boiled in a small quantity of water to dryness, it will be found that the sulphuric acid has been divided between the two bases in the compound ratio of their mass and their force of affinity. The greater part of the sulphate of barytes will be found undecomposed; a small quantity of barytes will be found at liberty; most of the potash will also be uncombined; but a certain portion will be united with the sulphuric acid which the barytes has lost in the form of sulphate of potash.

It is not merely in the instance stated here that this division of one body between two others, according to their respective masses and affinities, takes place, there being scarcely any example to the contrary.

And as the affinities of bodies vary with their masses, it is obvious, that when we speak of the affinities of bodies, we ought to consider them as always acting in certain determinate proportions.

Inferences....All the tables of affinities, which have so much engaged the attention of the moderns, and which are deceitful under the appearance of accuracy, are therefore merely comparative approximations to truth; for they have been constructed upon the supposition that dif-

ferent substances possess different absolute degrees of affinity to each other, capable of producing the decompositions and combinations which offer themselves, independently of the proportions of the bodies presented to each other. On the contrary, to determine the elective affinity of different bodies to each other, it is requisite to inquire what are the phenomena which they offer when presented to each other, in different proportions? These phenomena have hitherto been little attended to; nor has much attention been paid to other particular circumstances which appear capable of influencing the agency of affinity in general, namely, the action of light, electricity, galvanism, &c.

When these, and the before-mentioned discovery of Berthollet for determining the relative strength of affinity, are more attended to, they will probably lead to consequences of the greatest importance. It will oblige chemists to attend more closely to the reciprocal action of bodies on each other under different cirumstances; and the result must be, the discovery of several laws which will greatly facilitate the acquisition and the advancement of the science.

The rapid progress which chemistry has lately made, the multiplicity of its researches, and the scrupulous accuracy of observation with which experiments are now conducted, afford us every reason to hope that this will soon be accomplished. (*See Appendix No.* 7.)

HEAT, OR CALORIC.

(SEE APPENDIX NO. 8.)

PART X.

HEAT and cold are perceptions of which we acquire the ideas from the senses; they indicate only a certain state in which we find ourselves, independent of any exterior object. But as these sensations are for the most part produced by bodies around us, we consider them as causes, and, judging by appearances, we apply the terms *hot* or *cold* to the substances themselves; calling those bodies *hot* which produce in us the sensation of heat, and those *cold* which communicate the contrary sensation.

This ambiguity, though of little consequence in the common affairs of human life, has led unavoidably to confusion and perplexity in philosophical discussions. It was to prevent this that the framers of the new nomenclature adopted the word CALORIC, which denotes that which produces the sensation of heat.

SECT. I.

THEORIES OF HEAT.

TWO opinions have long divided the philosophical world concerning the nature of heat.

1. The one is, that the cause which produces the sensation of heat is a real or distinct substance, universally pervading nature, penetrating the particles or pores of all bodies with more or less facility, and in different quantities.

This substance, if applied to our system in a greater proportion than it already contains, warms it, as we call

it, or produces the sensation of heat; and hence it has been called *caloric* or *calorific*.

2. The other theory concerning heat is that the cause which produces that sensation is *not* a separate or self-existing substance; but that it is merely like gravity a property of matter; and that it consists in a specific or *peculiar motion, or vibration* of the particles of bodies.

The arguments in favour of the first theory have been principally deduced from the evolution and absorption of heat during chemical combinations; those of the latter are chiefly founded on the production of heat by friction. For it has been observed, that whatever is capable of producing motion in the particles of any mass of matter excites heat. Count Rumford* and Professor Davy† have paid uncommon attention to this fact, and proved, that heat continues to be evolved from a body subjected to friction, so long as it is applied, and the texture or form of the body be not altered.

All the effects of heat, according to this theory, depend therefore entirely on the vibratory motion of the particles of bodies. According as this is more or less intense, a higher or lower temperature is produced; and as it predominates over, is nearly equal, or inferior to the attraction of cohesion, bodies exist in a gaseous, fluid, or solid state.

Different bodies are susceptible of it in different degress, and receive and communicate it with different celerity. From the generation, communication, and abstraction of this repulsive motion under these laws, all the phenomena ascribed to heat are explicable.

Each of these theories has been supported by the most able philosophers, and given occasion to the most important disputes in which chemists have been engaged; and have contributed in a very particular manner to the advancement of the science. The obscurity of the subject, however, is such that both parties have been able to advance the most plausible arguments.

Setting aside all inquiries concerning the merits of these different doctrines, we shall confine ourselves to the general effects which heat produces on different

* Rumford's Essays, vol. iii.

† Davy's Essay in Beddoes's Medical Contributions.

bodies. For the phenomena which it presents, and their relation to each other, may be investigated with sufficient precision, though the materiality or immateriality of heat may remain unknown to us.

NATURE AND THEOREMS OF HEAT.

This premised, those who consider heat as matter, assert that caloric exists in two states, namely in combination, and in a radiant state or at liberty.

In the first state it is not sensible to our organs, nor indicated by the thermometer; it forms a constituent part of the body; but it may be brought back to the state of radiant or sensible heat. In this state it affects animals with the sensation of heat. It therefore has been called sensible or free heat, or fire; and is synonymous with uncombined caloric, thermometrical caloric, caloric of temperature, interposed caloric, &c. expressions now pretty generally superseded.

From the diversity of opinions among chemists respecting the nature of caloric several other expressions have been introduced, which it is proper to notice. For instance, by *specific heat* is understood the relative quantities of caloric contained in equal weights of different bodies at the same temperature. *Latent heat* is the expression used to denote that quantity of caloric which a body absorbs when changing its form. It is, however, more properly called *caloric of fluidity*. The disposition or property by which different bodies contain certain quantities of caloric, at any temperature, is termed their *capacity for heat*. By the expression of *absolute heat* is understood the whole quantity of caloric which any body contains. These terms shall be more fully considered hereafter.

Before we proceed further we shall briefly notice the various methods of exciting heat, and then endeavour to examine its general properties.

SECT. II.

METHODS OF EXCITING AND COLLECTING HEAT.

OF the different methods of exciting heat, the following are the most usual.

1. PRODUCTION OF HEAT BY PERCUSSION, OR COLLISION.

This method of producing heat is the simplest, and therefore it is generally made use of in the common purposes of life for obtaining fire.

When a piece of hardened steel is struck with a flint, some particles of the metal are scraped away from the mass, and so violent is the heat which follows the stroke, that it melts and vitrifies them. If the fragments of steel are caught upon paper and viewed with a microscope, most of them will be found perfect spherules, and very highly polished. Their sphericity demonstrates that they have been in a fluid state, and the polish upon their surface shows them to be vitrified.

This evolution of heat by percussion, seems to be the consequence of a permanent or temporary condensation of the body struck.

Mr. Dalton* has proved that when air is suddenly condensed, a thermometer surrounded by it rises several degrees. Mr. Mollett was the first who observed that a small piece of linen, rolled up, takes fire when put into the narrow canal in which the lower extremity of a pump for condensing air generally terminates.† Mr. Northmoore has inflamed phosphorus by condensed oxygen gas.‡

2. PRODUCTION OF HEAT BY COMPRESSION OR FRICTION.

Heat may likewise be excited by mere friction. Wood rubbed against wood, or against any hard body; metal

* Manchester Memoirs, v. 515. † Phil. Mag. xiv. 364.

‡ These experiments have produced the common tube and piston for firing spunk.

rubbed against metal, or against any other body; in short, solid bodies rubbed against each other are thereby heated, often so far as to become red hot. The natives of New Holland are said to produce fire in this manner with great facility, and spread it in a wonderful manner. For that purpose they take two pieces of dry wood, one is a stick about eight or nine inches long, and the other piece is flat; the stick they shape into an obtuse point at one end, and pressing it upon the other piece, they turn it very nimbly by holding it between both hands as we do a chocolate mill, often shifting their hands up and then moving them down upon it, in order to increase the pressure as much as possible. By this method they get fire in a few minutes, and from the smallest spark they increase it with great speed and dexterity.

If the irons at the axis of a coach-wheel are applied to each other without the interposition of some unctuous matter to keep them from immediate contact, they will become so hot when the carriage runs swiftly along, as to set the wood on fire; and the fore wheels being smallest and making most revolutions in a given time will be most in danger.

The same will happen to mill-work or to any other machinery.

It is no uncommon practice in this country for blacksmiths to use a plate of iron as an extemporaneous substitute for a tinder-box; for it may be hammered on an anvil till it becomes red hot, and will fire a brimstone match. A strong man who strikes quick, and keeps turning the iron so that both sides may be equally exposed to the force of the hammer, will perform this in less time than would be expected.

If in the coldest season one dense iron plate be laid on another, and pressed together by a weight, and then rubbed upon each other by reciprocal motions, they will gradually grow so hot, as, in a short time, to emit sparks, and at last become ignited.

It is not necessary that the substances should be very hard, a cord rubbed backwards and forwards swiftly against a post or a tree will take fire.

Count Rumford* and Professor Pictet† have made

* Nicholson's Journal (4th edit.) vol. ii. p. 106.
† Pictet's Essais sur le Feu, chap. ix.

some very ingenious and valuable experiments concerning the heat evolved by friction.

It is asserted, that heat may be produced by friction where there is absolutely no oxygen gas whatever; so that in these cases it cannot be derived from the decomposition of that gas. This has made several persons suspect that heat is not the effect of a peculiar substance, called caloric, but that it is only a peculiar motion or vibration of the particles of bodies. It must, however, be considered, that there is no friction which does not produce compression, viz. a contraction of the bulk of the bodies concerned, at least for a time, and therefore that the caloric is squeezed or forced out of the bodies themselves, and being communicated to the surrounding bodies, produces the usual signs of heat.

What very much corroborates this assertion is, that substances which are not compressible, are not heated by mechanical force; thus a flint will only be broken, but a piece of metal will be heated by the strokes of a hammer. Thus, also, we may place any weight upon a quantity of water without altering its temperature, because the compressibility of that fluid is almost nothing; but if we place an additional weight upon a quantity of air, the bulk of that fluid will be contracted, and its temperature will be raised by the compression.

3. PRODUCTION OF HEAT BY CHEMICAL ACTION.

To this belongs the heat produced by combustion. There are besides this many chemical processes wherein rapid chemical action takes place accompanied with a development of heat, or fire and flame. Instances of this kind have been noticed already, page 51. More striking experiments will be given in the progress of this work.

It has been remarked, that whenever a mixture of two or more bodies is attended with heat, the bulk of that mixture is less than the sum of the bulk of the separate ingredients, viz. a compression or concentration takes place, which is accompanied with a development of caloric; viz. if 100 grains of alcohol, of 0,825 specific gravity, occupy a space equal to 100, at a temperature of

60° Fahr. and 100 grains of water, at the same temperature, occupy a volume equal to 82,5 the volume of these two fluids, after being mingled and reduced to the original temperature, viz. 60°, will be 177,41; a diminution of bulk equal to 5,09 has therefore taken place. The specific weight of the mixture is 0,93,002.

4. SOLAR HEAT.

It is well known that every lens, whether convex or plano-convex, will collect by refraction the rays of the sun dispersed over its surface into one point or focus, and produce the most astonishing effects.

Dr. Herschell has discovered, that there are rays emitted from the sun which have not the power of illuminating or producing vision; and that these are the rays which produce the heat of the solar light, besides others which have a deoxydating power.

Consequently heat is emitted from the sun in rays; but these rays are not the same with the rays of light, as shall be more fully proved hereafter.

The direct rays of the sun on the same spot of the surface of the earth are more or less hot according to the time of the year, clearness of the atmosphere, state of the wind, and the colour, together with the quality of the spot. On this island, and in the hottest time of the summer, the direct rays of the sun seldom raise the thermometer so high as 110°. In other climates, especially within the tropics, they raise the thermometer considerably higher, viz. 20 or 30, or as it is said, even 40° higher than 110. But we must not believe the idle stories of their melting lead, or even of their setting fire to gunpowder.

No sensible heat is known to be derived from any other celestial body. The moon, indeed, on account of the great light it reflects on the earth, might be expected to communicate some degree of heat; but though that light, concentrated by a large concave mirror, has been thrown upon the most sensible thermometers, yet I am not certain that it ever affected them. A great many calculations have been made concerning the proportion between the light which we receive directly from the

sun, and that which is reflected to us from the moon; from which it appears that the latter is several hundred times less dense than the former; and the heat of both is supposed to be in the same proportion.

5. PRODUCTION OF HEAT BY THE ELECTRIC SPARK, AND BY GALVANISM.

The effects of electricity are too well known in this point of view to need any description.

Galvanism has of late become a powerful instrument for the purpose of exciting heat. Not only easily inflammable substances, such as phosphorus, sulphur, &c. have been fired, but likewise gold, silver, copper, tin, and the rest of the metals, have been burnt by means of galvanism, as was shown by professor Davy in his lectures at the theatre of the Royal Institution.

Such are the principal methods of exciting heat. We shall now endeavour to examine experimentally the effects which heat produces upon bodies in general.

SECT. III.

GENERAL EFFECTS OF HEAT.

EXPANSIVE PROPERTY OF HEAT.

This is the first and most obvious effect which heat produces on bodies. Experience has taught us, that at all times when bodies become hot they increase in bulk. The bodies experience a dilatation which is greater in proportion to the accumulation of caloric, or, in other words, to the intensity of the heat. This is a general law which holds good as long as the bodies have suffered no change either in their combination or the quantity of their chemical principles.

This power which heat possesses consists therefore in a constant tendency to separate the particles of bodies. Hence philosophers consider heat as the *repulsive power*

which acts upon all bodies whatever, and which is in constant opposition to the power of attraction.

The phenomena which result from these mutual actions seem as it were the secret springs of nature. Heat, however, does not expand all bodies equally, and we are still ignorant of the laws which it follows.

1. EXPANSION OF FLUID BODIES BY HEAT.

Experiment I.

Take a glass globe, with a long slender neck called a bolt head, fill it up to the neck with water, ardent spirit, or any other fluid which may be coloured with red or black ink, in order to be more visible, and then immerse the globe of the instrument in a vessel of hot water; the included fluid will instantly begin to mount into the neck. If it be taken out of the water and brought near the fire, it will ascend more and more in proportion as it becomes heated; but upon removing it from the source of heat, it will sink again: a clear proof that caloric dilates it, so as to make it occupy more space when hot than when cold. These experiments may therefore serve as a demonstration that heat expands *fluid* bodies.

It appears that liquids of the least density expand most with the same temperature. Thus hydrogen gas dilates more with the same degree of heat than atmospheric air; atmospheric air more than sulphuric ether; ether more than ardent spirit; ardent spirit more than oil; oil more than water; water more than acids; and acids more than mercury. But if we compare the periods of time necessary for each fluid to acquire the *maximum* of rarefaction it is susceptible of, there is no law to guide us yet known.

2. EXPANSION OF AERIFORM BODIES BY HEAT.

Experiment I.

The expansion of air, or any other gaseous fluid, may be evinced in the following manner: let a glass retort be supported on the ring of the lamp-furnace, so as to suffer the neck of it to dip into a basin of water; if heat be now

applied to the retort by means of the lamp, the confined air in the retort will expand, and bubbles of air will pass through the water.

NATURE OF THE AIR-THERMOMETER, OR MANOMETER.

This instrument, in which the expansion of air is tried, has been called *manometer*, but in truth it is only an air-thermometer, and though rather larger, it is not, however, unlike the common thermometer, viz. it consists of a tube five or six feet long, having a bulb at one end and open at the other. The bore of the tube is about a 20th of an inch in diameter. A small quantity of quicksilver is placed in some part of the cavity of the tube, and the expansion of the air of the bulb, when heated, forces the quicksilver to move towards the open end of the tube. The degree of heat to which the manometer is exposed, is measured by means of a thermometer; the quantity of expansion of the air is ascertained by gauging the manometer, and making marks on the tube, which marks may indicate parts of the cavity of the tube that are proportional to the capacity of the manometer, as, for instance, 100ths or 1000ths, &c.

By placing the manometer horizontal or vertical, either with the bulb downwards or the bulb upwards, the air in it may be either left of the natural density, or it may be condensed, or, lastly, it may be rarified; for when the manometer is horizontal, the quicksilver does neither press upon the air of the manometer, nor on that of the atmosphere; when the bulb is downwards the quicksilver presses upon the air of the manometer: and when the bulb is upwards, the quicksilver presses against, and counteracts, in some measure, the gravity of the atmosphere. Hence this pressure and this rarefaction of the air within the manometer may be increased to any required degree by increasing the quantity of the quicksilver within the tube; and thus the expansibility of common, or of condensed, or of rarified air may be tried.

The expansion of air by the same degrees of heat, differs according to its density, and to the quantity of moisture it contains; nor are the increments of its bulk proportional to the degrees of temperature.

It appears from colonel Roy's very numerous experiments,* that 1000 parts of air, of the density of the common atmosphere, at 0° of heat, become 1484,21 at 212°, viz. are expanded 484,21 by 212° of heat.

1000 parts of air loaded with $2\frac{1}{2}$ atmospheres, are expanded 434 of those parts by 212° of heat.

1000 parts of air pressed only with $\frac{5}{6}$ of an atmosphere, are expanded nearly 484 of those parts by 212° of heat.

1000 parts of air pressed with $\frac{1}{2}$ of an atmosphere are expanded about 141 parts by 180° of heat, viz. from the freezing to the boiling point.

"From these last experiments," says colonel Roy, "it would seem, that the particles of air may be so far removed from each other, by the diminution of pressure, as to lose a very great part of their elastic force."

The above-mentioned expansions are by no means regular; viz. they are not proportional to the number of degrees of heat. The maximum of expansion takes place between 52° and 72°, and the minimum is constantly at the boiling point of water.

Moist air expands vastly more than dry air, especially when it approaches the boiling point of water; so that between 192° and 212°, moist air expands about 8 or 9 times as much as dry air in similar circumstances.

On the expansibility of air is founded Schmidt's pyrometer.

Let atmospheric air be freed from moisture by caustic alkalies, or other bodies, and included in a vessel of platina. This vessel A (fig. 3, pl. VI.) which may be made of any convenient size, is connected with the tube BB, of as fine a bore as possible. This tube is also made of platina, and reaches into a vessel C, which is filled with water up to *e e*, and into this the tube is fixed air-tight. Out of the vessel C rises a glass cylinder G hermetically sealed, including a thermometer, and a graduated tube F F is secured into the vessel C in a similar manner.

Experiment II.

If a bladder be partly filled with air, and the neck of it closely tied, so as to prevent the inclosed air from

* Philosophical Transactions, vol. lxvii. art. xxxiv.

escaping, and be held near a fire, the air will soon begin to occupy more space, and the bladder will become gradually distended; on continuing the expansion of the air by increasing the heat, the bladder will burst with a loud report.

3. EXPANSION OF SOLID BODIES BY HEAT.

Experiment I.

If we take a bar of iron six inches long, and put it into a fire till it becomes red-hot, and then measure it in this state accurately, it will be found $\frac{1}{120}$ of an inch longer than it was before; that is, about 120th part of the whole. That the metal is proportionably expanded in breadth, will be seen by trying to pass it through an aperture which it fitted exactly when cold, but which will not admit it when red-hot. The bar is therefore increased in length and diameter.

To discover the minutest changes of expansion of heat, and the relative properties thereof, instruments have been contrived called *pyrometers*, the sensibility of which is so delicate as to show the expansion from $\frac{1}{50000}$ to $\frac{1}{100000}$ of an inch.

INFERENCES.

It is owing to this expansion of metals that the motion of time pieces is rendered erroneous; but the ingenuity of artists has discovered methods of obviating this inaccuracy, by employing the greater expansion of one metal to counteract the expansion of another; this is effected in what is called the gridiron pendulum. Upon the same principle a particular construction of watches has been contrived.

The expansion of metals is likewise one of the principal reasons that clocks and watches vary in winter and summer, when worn in the pocket, or exposed to the open air, or when carried into a hotter or a colder climate. For the number of the vibrations of the pendulum, are always in the sub-duplicate ratio of its length, and as the length is changed by heat and cold, the times of vibration will be also changed. The quantity of alteration, when considered

in a single vibration, is exceedingly small, but when they are often repeated it will be very sensible. An alteration of one thousandth part in the time of a single vibration of a pendulum which beats seconds, will make a change of eighty-six whole vibrations in twenty-four hours.

As different metals expand differently with the same degree of heat; such musical instruments, therefore, whose parts are to maintain a constant true portion, should never be strung with different metals. It is on this account that harpsichords, &c. are out of tune by a change of temperature.

Bodies which are brittle, or which want flexibility, crack or break if suddenly heated or cooled. This likewise depends upon the expansive force of heat, stretching the surface to which it is applied, while the other parts not being equally heated, do not expand in the same ratio, and are therefore torn asunder, or break. Hence thin vessels stand heat better than thick ones.

SECT. IV.

MEASUREMENT OF HEAT.

Upon the expansive property of heat, which we have considered before, is founded its artificial measurement. Various means have been therefore employed to assist the imperfection of our sensations in judging of the different degrees of heat, for our feelings unaided afford but very inaccurate information concerning this matter; they indicate the presence of *heat*, only when the bodies presented to them are *hotter* than the actual temperature of our organs of feeling. When those bodies are precisely of the same temperature with our body, which we make the standard of comparison, we then are not sensible of the presence of heat in them. When their temperature is less hot than that of our bodies, their contact gives us what is called the sensation of cold.

The effects of heat upon material bodies in general which are easily visible to us, afford more precise and determinate indications of the intensity, than can be derived from our feelings alone. The ingenuity of the philoso-

pher and artist has therefore furnished us with instruments for measuring the relative heat or temperature of bodies. These instruments are called *thermometers* and *pyrometers.* By these all degrees are measurable, from the slightest to that of the most intense heat.

NATURE OF THE THERMOMETER.

A thermometer is a hollow tube of glass, hermetically sealed and blown at one end in the shape of a hollow globe. The bulb and part of the tube are filled with mercury, which is the only fluid which expands equally. When we immerse the bulb of the thermometer in a hot body, the mercury expands, and of course *rises* in the tube; but when we plunge it into a cold body, the mercury contracts and of course *falls* in the tube.

The rising of the mercury indicates, therefore, an increase of heat; its falling, a diminution of it; and the quantity which it rises or falls, denotes the proportion of increase or diminuition. To facilitate observation, the tube is divided into a number of equal parts called degrees.

Further, if we plunge a thermometer ever so often into melting snow or ice, it will always stand at the same point. Hence we learn that *snow* or *ice* always begins to melt at the same temperature.

If we plunge a thermometer repeatedly into water kept boiling, we find that the mercury rises up to a certain point. This is therefore the point at which water always boils, provided the pressure of the atmosphere be the same.

There are four different thermometers used at present in Europe, differing from each other in the number of degrees into which the space between the freezing and boiling points is divided. These are Fahrenheit's, Reaumur's, Celsius's, and Delisle's.

The thermometer uniformly used in Britain is Fahrenheit's: in this the freezing point is fixed at 32°; the boiling point at 212° above 0°, or the part at which both the ascending and descending series of numbers commence.

In the thermometer which was first constructed by Reaumur, the scale is divided into a smaller number of degrees upon the same length, and contains not more than 80° between the freezing and the boiling points. The freezing point is fixed in this thermometer precisely at 0°,

the term between the ascending and the descending series of numbers. 100 is the number of the degrees between the freezing and the boiling points in the scale of Celsius; which has been introduced into France since the revolution, under the name of the centigrade thermometer; and the freezing point is in this as in the thermometer of Reaumur fixed at 0°. One degree in the scale of Fahrenheit appears from this account to be equal to $\frac{4}{9}$ of a degree on that of Reaumur, and to $\frac{5}{9}$ of a degree on that of Celsius.

The space in Delisle's thermometer between the freezing and boiling points is divided into 150°, but the graduation begins at the boiling point and increases towards the freezing point. The boiling point is marked 0, the freezing point 150°. Hence 180 F. = 153 D. or 6 F. = 5 D. To reduce the degrees of Delisle's thermometer *under* the boiling point to those of Fahrenheit; we have F. = $212 - \frac{6}{5}$ D.; to reduce those *above* the boiling point F. = $212 + \frac{6}{5}$ D. Upon the knowledge of this proportion it is easy for the student to reduce the degrees of any of these thermometers into the degrees of any other of them. For chemical purposes the ball and part of the tube should project some way below the graduated seats, in order that they may be placed in liquids, mixtures, &c.

NATURE OF THE DIFFERENTIAL THERMOMETER.

This instrument, for which we are indebted to Mr. Leslie, is calculated for measuring the minutest variation of temperature. Mr. Leslie's differential thermometer consists of two glass tubes, each terminating in a small bulb of the same dimensions, joined by the blow-pipe, and bent in the form of an U, a small portion of dark-coloured liquor (sulphuric acid, tinged red with carmine) having previously been introduced into one of the balls. By managing the included air with the heat of the hand, this red liquor is made to stand at the point required of the opposite tube. This is the zero of a scale fastened to that tube, and divided into equal parts above and below nothing. The instrument is then fixed upright on a stand. It is manifest, that when the liquor is at rest, or points at zero, the column is pressed opposite ways by two

portions of air, equal in elasticy, and containing equal quantities of caloric. Whatever heat, then, may be applied to the whole instrument, provided both bulbs receive it in the same degree, the liquor must remain at rest. But if the one ball receives the slightest excess of temperature, the air which it contains will be proportionably expanded, and will push the liquid against the air in the other bulb with a force, as the difference between the temperatures of those two portions of air. The equilibrium, in short, will be destroyed, and the fluid will rise in the opposite tube. The degrees of the scale through which it passes will mark the successive augmentations in the temperature of the ball, which is exposed to the greatest heat. This instrument, therefore, is truly a balance of extreme delicacy, for comparing the temperatures with which its two scales may be loaded.

NATURE OF THE PYROMETER.

To measure those higher degrees of heat to which the thermometer cannot be applied, there have been other instruments invented by different philosophers; these are called *pyrometers*. The most celebrated instrument of this kind, and which has been adopted into general use, is that invented by the late ingenious Mr. Wedgwood.

This instrument is also sufficiently simple. It consists of two pieces of brass fixed on a plate so as to be $\frac{6}{10}$ of an inch asunder at one end, and $\frac{3}{10}$ at the other: a scale is marked upon them, which is divided into 240 equal parts, each $\frac{1}{10}$ of an inch; and with this his gauge are furnished a sufficient number of pieces of baked clay, which must have been prepared in a red heat, and must be of given dimensions. These pieces of clay, thus prepared, are first to be applied cold, to the rule of the gauge, that there may no mistake take place in regard to their dimensions. Then any one of them is to be exposed to the heat which is to be measured, till it shall have been completely penetrated by it. It is then removed and applied to the gauge. The difference between its former and its present dimensions will show how much it has shrunk; and will, consequently, indicate to what degree the intensity of the heat to which it was exposed amounted.

High temperatures can thus be ascertained with accuracy. Each degree of Wedgwood's pyrometer is equal to 130° of Fahrenheit's.

Guyton has lately invented a pyrometer for measuring the highest degrees of heat of our furnaces, consisting of a lever of platina moved by the expansion of a bar of the same metal, the whole being supported on a mass of baked clay. It consists of a rod of platina placed horizontally in a groove formed in a cake of white clay highly baked. This plate is supported at one of its extremities on the part of the mass which terminates the groove; the other end presses against a bended lever, whose longest arm forms an index to a graduated arc; so that the change of position of this index indicates the expansion produced on the plate of metal by the heat.

The cake of clay having been highly baked, leaves no cause to apprehend any contraction; and the expansion which may take place during the ignition will only effect the very small distance between the axis of motion of the index and the point of contact of the plate, that is to say, in such a manner as rather to diminish the effect than to increase it.

All the parts of this instrument being of platina, neither fusion nor oxydation is to be apprehended.

With respect to its dimensions, the author conceives that, in order to render the use of it commodious and accurate, they should be reduced to such as may be necessary to obtain sensible variations; it will then be rendered commodious by the facility with which it may be placed under a muffle or an inverted crucible, &c. and accurate, because the probabilities of any accidental inequalities of the heat will be diminished, which it is impossible to avoid to a certain extent, even in the midst of a large mass of fire.

The variations will be sufficiently preceptible, if we can not only estimate, but correctly determine expansions of the 200th part of a millimetre (about the 500th part of an inch) these the author obtains by the proportions of the instrument which he has himself adopted.

The rod or plate of expansion is 45 millimetres (one inch and three quarters) in length, 5 in width (one fifth of an inch) and 2 in thickness (one thirteenth of an inch.)

The arm of the bended lever, which presses against the

end of this rod, is 25 millimetres in length; (rather $2\frac{1}{3}$, or about one ninth of an inch) and the arm at right angles to it, or the index, which traverses on the graduated arc, is 50 millimetres in length (one inch and eight tenths) or twenty times the length of the other. The space traversed by the displacing of the small arm will be thus increased in the proportion of 1 to 20.

As the long arm or index carries a nonius which divides each degree on the graduated arc into ten parts, we can distinctly observe the 200th of one of those measures (referred to the bar itself.)

Lastly: as the decimal division of an arc of a circle of 50 millimetres radius, gives only 7.8538 deci-millimetres for one of its degrees, it is evident, then, that we may measure an expansion of 0.078538 deci-millimetres, or of the 5730th parth of the length of the radius.

In order to prevent the position of the index from being changed in removing the instrument from the furnace, a plate of platina is fixed so as to form a spring against its extremity.

The author has commenced a series of experiments to determine the range of this pyrometer, to compare it with the pyrometic pieces of Wedgwood, and so to show the degree of confidence it merits, the methods of using, and the cases in which it may be usefully employed in philosophical researches, and in the arts.

SECT. V.

EXCEPTIONS TO THE EXPANSION BY HEAT.

Philosophers have noticed a few exceptions to the law of heat expanding bodies. For instance, water when cooled down to the freezing point, instead of contracting on the further deprivation of heat, actually expands.

Another seeming exception is manifested in alumine or clay; others occur in the case of cast iron, and various other metals. Alumine contracts on being heated, and cast-iron, bismuth, &c. when fully fused are more dense than when solid; for as soon as they become so they decrease in density: they expand in the act of cooling; and

hence the sharpness of figures upon iron which has been cast in moulds, compared to that of other metals.

Some philosophers have persuaded themselves that these exceptions are only *apparent*, but not really true. They say when water freezes, it assumes a crystalline form, the crystals cross each other and cause numerous vacuities, and thus the ice occupies more space. The same is the case with fused iron, bismuth, and zinc. The contraction of clay is owing to the loss of water, of which it loses a part at every increased degree of temperature hitherto tried: there is, therefore, a loss of matter; and a reduction of volume must follow.

Mr. Tilloch* has published a brief examination of the received doctrines respecting heat and caloric, in which these truths are more fully considered, together with many other interesting facts relative to the received notions of heat.

SECT. VI.

EQUAL DISTRIBUTION OF HEAT.

It was stated before that all bodies are permeable to heat, and that it has a constant tendency to diffuse itself over matter till an equilibrium of temperature is established. It is impossible to accumulate it in any body beyond a certain degree, or to preserve it in that accumulated state.

If, therefore, a number of bodies of different temperatures are placed in contact with each other, they will all at a certain time acquire a temperature which is the mean temperature of the different substances; the caloric of the hottest body will diffuse itself among those which are heated in a less degree till they have all acquired a certain temperature. Thus, if a bar of iron which has been made red-hot be kept in the open air, it does not retain the heat which it had received, but becomes gradually colder and colder, till it arrives at the temperature of the bodies in its neighbourhood. On the other hand, if we cool down the iron bar by keeping it for some time covered with

* Philosophical Magazine, May, 1800, p. 78.

snow, and then carry it into a warm room, it does not retain its low temperature, but becomes gradually hotter till it acquires the temperature of the room. It is therefore obvious that in the one instance the temperature is lowered, and in the other that it is raised.

These changes of temperature occupy a longer or a shorter time according to the nature of the body, but they always take place at last. This law itself is indeed familiar to every one: when we wish to heat a body we carry it towards the fire; when we wish to cool it we surround it by cold bodies.

This distribution of heat takes place even through the Torricelian vacuum, and it is evidently owing to its repulsive power, which constantly tends to an equilibrium.

SECT. VII.

PROPAGATION OF HEAT.

We have seen in the last section that when bodies of higher temperature than others are brought into contact with each other, the heat is propagated from the first to the second, or the colder body deprives the warmer of its excess of heat. We shall now see that some bodies do so much more quickly than others. Through some bodies caloric passes with undiminished velocity; through others its passage is prodigiously retarded.

This disposition of bodies of admitting under equal circumstances the refrigeration of a heated body within a shorter or a longer time, is called *the power of conducting heat*; and a body is said to be a *better* or *worse conductor of heat*, as it allows the refrigeration to go on quicker or slower. Those bodies, therefore, which possess the property of letting heat pass with facility are called *good conductors*; those through which it passes with difficulty are called *bad conductors*; and those through which it does not seem to pass at all are called *non-conductors*: thus we say in the common language, some bodies are *warm* or capable of preserving warmth; and from this arises the great difference in the sensations excited by different bodies, when applied at the same temperature to

our organs of feeling. Hence if we immerse our hand in mercury we feel a greater sensation of cold than when we immerse it in water, and a piece of metal appears to be much colder than a piece of wood, though their temperatures when examined by means of the thermometer are precisely the same.

It is probable that all solids conduct heat in some degree, though they differ very much in their conducting power. Metals are the best conductors of heat; but the conducting powers of these substances are by no means equal. Stones seem to be the next best conductors. Glass conducts heat very slowly; wood and charcoal still slower; and feathers, silk, wool, and hair, are still worse conductors than any of the substances yet mentioned.

The best conductors of electricity and galvanism are also the best conductors of heat.

Experiment I.

Take a number of straight wires of equal diameters and lengths, but of different metals, for instance, gold, silver, copper, iron, &c. cover each of them with a thin coat of wax or tallow, and plunge their extremities into water kept boiling, or into melted lead. The melting of the coat of wax will show that caloric is more quickly transmitted through some metals than others.

It is on this account, also, that the end of a glass rod may be kept red-hot for a long time, or even melted without any inconvenience to the hands which holds the other extremity; though a similar metallic rod heated in the same manner would very soon become too hot to be held.

The preceding observations apply only to the conducting power of solids. With respect to fluids, two opinions are at present entertained; one which considers them as capable of conducting caloric, though very imperfectly; the other which supposes them absolutely impermeable to this power.

Count Rumford was the first who endeavoured to prove that fluids in general, and aeriform bodies, convey heat on a different principle from that observed in solids. According to this philosopher, caloric is propagated through fluids solely by the successive and actual application of the fluid

to the heated part, and the portion so heated gives none of its caloric to the rest of the mass. Although the particles of any fluid individually can receive heat from other bodies, or communicate it to them, yet among these particles themselves, all *interchange* and communication of heat is absolutely impossible. Fluids, therefore, according to count Rumford, are perfectly non-conductors of heat.

It may appear at first sight that fluids are conductors, for they can be heated as well as solids, and heated too considerably without sensibly changing their state of existence. But fluids differ from solids in one essential particular: their particles are at full liberty to move among themselves, and they obey the smallest impulse; while the particles of solids, from the very nature of these bodies, are fixed and stationary. One of the changes which caloric produce is, as stated before, expansion, or increase of bulk; and this increase is attended with a proportional diminution of specific gravity. Therefore, whenever caloric combines with a stratum of particles, the whole stratum becomes specifically lighter than the other particles. This produces a change of situation in solids; but in fluids, if the heated stratum happens to be below the other strata, it is pressed upwards by them, and being at liberty to move, it changes its place and is urged up to the surface.

In fluids, then, it makes a very great difference to what part of the body the source of heat is applied. If it be made to act at the highest stratum of all, or to the surface of the liquid, the caloric can only make its way downwards, as through solids, by the conducting power of the fluid; but if it be applied to the lowest stratum, it makes its way upwards independent of that conducting power, in consequence of the fluidity of the body, and the expansion of the heated particles. The lowest stratum, as soon as it combines with a dose of caloric, becomes specifically lighter and ascends. New particles approach the source of heat; combine with it in their turn, and are displaced. In this manner all the particles come one after another to the source of heat; of course the whole of them are heated in a very short time, and the caloric is *carried* almost at once to much greater distances in fluids than in any solid whatever. Fluids, therefore, have the property

of *carrying* or *transporting* caloric; in consequence of which they acquire heat, independent altogether of any conducting power, according to count Rumford's theory, and hence all fluids are considered by him, as stated before, in a similar respect as absolutely *non-conductors* of caloric. They can receive it from substances, and can give it to other bodies, but no particle can either receive it from, or give it to, another particle. Before a fluid, therefore, can be heated or cooled, every particle, as stated before, must go individually to the very substance from which it receives, or to which it gives, caloric. Heat being therefore *only* propagated in fluids in consequence of the internal motion of their particles which transport the heat; the more *rapid* these motions are, the *more* rapid is the communication of heat. The cause of these motions is the change in the specific gravity of the fluid, occasioned by the change of temperature, and the rapidity is in proportion to the change of the specific gravity of the liquid by any given change of temperature. The following experiment has been advanced to illustrate these facts.

Experiment II.

Take a thin glass tube, eight or ten inches long, and about an inch in diameter. Pour into the bottom part for about the depth of one inch, a little water coloured with Brazilwood or litmus, and then fill up the tube with common water, extremely gently, so as to keep the two *strata* quite distinct from each other. Having done this, heat the bottom part of the tube over a lamp, the coloured infusion will then ascend and gradually tinge the whole fluid; the water in the upper part of the tube may be made to boil, but the colouring matter will remain at the bottom undisturbed. The heat cannot act downwards to make it ascend.

By thus being able to make the upper part of a fluid boil, without heating the bottom part, water may be kept boiling for a considerable time in a glass tube over ice without melting it.

Other experiments illustrating the same principle may be found in count Rumford's Essays, especially in essay the 7th, 1797.

The results of his experiments, which are contained in the above essay, are highly interesting; but experiments lately made on the same subject, have sufficiently convinced us, that the Count's position is founded in error; they do not prove that fluids are non-conductors, but rather the contrary: all liquids whatever are capable of conducting caloric. When the source of heat is applied to their surface, the caloric gradually makes its way downwards, and the temperature of every stratum gradually diminishes from the surface to the bottom of the liquid. The increase of temperature, in this case, is not owing to the carrying power of the fluid. By that power, caloric may, indeed, make its way upwards through fluids, but certainly not downwards. Liquids, then, are conductors of caloric. This, however, will become more evident from the following experiments made by Dr. Thompson and Mr. Murray, and Mr. Dalton.

That liquids are conductors of caloric, Dr. Thompson proved in the following manner. The liquid whose conducting power was to be ascertained, was poured into a glass vessel till it filled it about half way; then a hot liquid of a less specific gravity was poured over it. Thermometers were placed at the surface, in the centre, and at the bottom of the cold liquid; if these rose, it followed that the liquid was a a conductor, because the caloric made its way downwards. For instance, to examine the conducting power of mercury, a glass jar was half filled with that metal, and boiling water then poured over it. The thermometer at the surface began immediately to rise, then the thermometer at the centre, and lastly that at the bottom. The first rose to 118°, the second to 90°, the third to 86°: the first reached its maximum in 1′, the second in 15′, the third in 25′. The conducting power of water was tried in the same manner, only hot oil was poured over it. A variety of precautions were necessary to ensure accuracy; but for these we refer the reader to the experiments themselves, which are detailed in Nicholson's Journal.*

These facts have been since confirmed by a very ingeniously contrived and convincing experiment made by Mr.

* Nicholson's Journal, iv. s. 29.

Murray. To prevent the possibility of any heat being conducted by the apparatus, he employed a vessel of ice, which is incapable of conducting any degree of heat greater than 32°. In this vessel Mr. Murray made experiments of the same nature with those just mentioned, and the result was the same. The thermometer constantly rose upon the application of a hot body to the surface of the liquid in which the thermometer was standing.* Mr. Dalton has likewise published lately a set of experiments almost exactly of the same nature with Dr. Thompson's, and with the same result. From the date affixed to his paper we learn, that his experiments had been made, and an account of them read to the Manchester Society just about the same time that Dr. Thompson was drawing up an account of his; though they were not published till about two years after.†

Fluids, then, so far as experiments have been made, are conductors of caloric as well as solids. Hence it follows that all bodies with which we are acquainted are capable of conducting caloric.

On the bad conducting power of different bodies is founded the well-known facts, that of the different substances used in clothing, hares fur and eider-down are the warmest; next to these, beavers fur, raw silk, sheeps wool, cotton-wool, and, lastly, lint or the scrapings of fine linen. In fur the air interposed among its particles is so engaged as not to be driven away by the heat communicated thereto by the animal body; not being easily displaced, it becomes a barrier to defend the animal body from the external cold.

Hence it is obvious that those skins are warmest which have the finest, longest, and thickest fur; and that the furs of the beaver, otter, and other like quadrupeds which live much in the water, and the feathers of water-fowl, are capable of confining the heat of those animals in winter, notwithstanding the coldness of the water which they frequent.

Bears, and various other animals, inhabitants of cold climates, which do not often take the water, have their fur much thicker on their backs than on their bellies.

* Manchester Memoirs, V. † Ibid. 8vo. 1.

The snow, as a light porous body, which covers the surface of the earth in winter in high latitudes, is doubtless designed as a garment to defend it against the piercing winds from the polar regions which prevail during the cold season.

Without dwelling further upon the philosophy of this truth, we must briefly remark that the happy application of this law satisfactorily elucidates some of the most interesting facts of the economy of nature.

SECT. VIII.

THEORY OF CALORIC OF FLUIDITY, OR LATENT HEAT.

THERE are some bodies which, when submitted to the action of caloric, dilate to such a degree, and the power of aggregation subsisting among their particles is so much destroyed and removed to such a distance by the interposition of caloric, that they slide over each other in every direction, and therefore appear in a fluid state. This phenomenon is called *fusion*. Bodies thus rendered fluid by means of caloric are said to be *fused*, or *melted*; and those that are subject to it are called *fusible*.

The greater number of solid bodies may, by the application of heat, be converted into fluids, and most probably all would be so were we able to excite a sufficient degree of heat. Thus metals may be fused; sulphur, resin, phosphorus, may be melted; ice may be converted into water, &c.

Those bodies which cannot be rendered fluid by any degree of heat hitherto known are called *fixed*, or *infusible*.

If the effects of heat under certain circumstances be carried still further than is necessary to render bodies fluid, vaporization begins; the bodies then become converted into the vaporous or *gaseous state*. Vaporization, however, does not always require a previous fusion. Some bodies are capable of being converted into the vaporous

state without previously becoming fluid, and others cannot be volatilized at any temperature hitherto known.

Fluidity is, therefore, by no means essential to any species of matter, but always depends on the presence of a quantity of caloric. Solidity is the natural state of all bodies, and there can be no doubt that every fluid is capable of being rendered solid by a due reduction of temperature; and every solid may be fused by the agency of caloric, if the latter do not decompose them at a temperature inferior to that which would be necessary for their fusion.

CALORIC OF FLUIDITY.

Dr. Black was the first who proved that whenever caloric combines with a solid body, the body becomes heated only until it is rendered fluid; or that whenever it has acquired the fluid state its temperature remains stationary, though caloric is continued to be added to it. The same is the case when fluids are converted into the aeri[form] form or vaporous state.

From these facts the laws of latent heat have been inferred. The theory may be illustrated by means of the following experiments:

Experiment I.

If a lump of ice at a low temperature, suppose at 22°, be brought into a warm room, it will become gradually less cold, as may be discovered by means of a thermometer. After a very short time it will reach the temperature of 32° (the freezing point) but there it stops. The ice then begins to melt; but the process goes on very slowly. During the whole of that time its temperature continues at 32°; and, as it is constantly surrounded by warm air, we have reason to believe that caloric is constantly entering into it; yet it does not become hotter till it is changed into water. Ice, therefore, is converted into water by a quantity of caloric uniting with it.

It has been found by calculation that one pound of ice in melting absorbs 140° of caloric, the temperature of the water produced still remaining at 32°.

This fact may be proved in a direct manner.

Experiment II.

Take one pound of ice at 32° reduced to a coarse powder; put it into a wooden bowl, and pour over it gradually one pound of water heated to 172°; all the ice will become melted, and the temperature of the whole fluid, if examined by a thermometer, will be 32°: 140° of caloric are therefore lost, and it is this quantity which was requisite to convert the ice into water.

This caloric has been called *latent caloric*, or rather caloric of fluidity; because its presence is not measurable by the thermometer.

Dr. Black has also ascertained by experiment, that the fluidity of melted wax, tallow, spermaceti, metals, &c. is owing to the same cause, and Ladriani proved that this is the case with sulphur, alum, nitrate of potash, &c.

We consider it therefore as a general law, that whenever a solid is converted into a fluid, it combines with caloric, and that is the cause of fluidity.

On the sudden transition of solids into fluids is founded the well known

PRODUCTION OF ARTIFICIAL COLD, BY MEANS OF FRIGORIFIC MIXTURES.

A number of experiments have been lately made by different philosophers, in order to produce artificial cold. And as these methods are often employed in chemistry with a view to expose bodies to the influence of very low temperatures, we shall enumerate the different substances which may be made use of for that purpose, and the degrees of cold which they are capable of producing. We are indebted for them to Pepys, Walker, and Lowitz.

TABLE OF FREEZING MIXTURES.

Mixtures.	*Thermometer sinks.*
Muriate of ammonia 5 parts Nitrate of potash . . 5 Water 16	From 50° to 10°.
Muriate of ammonia 5 parts Nitrate of potash . . 5 Sulphate of soda . . 8 Water 16	From 50° to 4°.
Sulphate of soda . . 3 parts Diluted nitric acid . 2	From 50° to 3°.
Sulphate of soda . . 8 parts Muriatic acid . . . 5	From 50° to 0°.
Snow . . . . . 1 part Muriate of soda . . 1	From 32° to 0°.
Snow or pounded ice 2 parts Muriate of soda . . 1	From 0° to — 5°.
Snow or pounded ice 1 part Muriate of soda . . 5 Muriate of ammonia & Nitrate of potash . . 5	From — 5° to — 18°.

TABLE OF FREEZING MIXTURES CONTINUED.

Mixtures.	*Thermometer sinks.*
Snow or pounded ice 12 parts Muriate of soda . 5 Nitrate of ammonia 5	From—18° to—25°.
Snow and Diluted nitric acid	From 0° to—46°.
Muriate of lime . 3 parts Snow 2	From 32° to—50°.
Potash . . . . 4 parts Snow 3	From 32°. to—51°.
Snow . . . . . 2 parts Diluted sulphuric acid 1 Diluted nitric acid 1	From—10° to—56°.
Snow . . . . . 1 part Diluted sulphuric acid 1	From 20° to—60°
Muriate of lime . 2 parts Snow 1	From 0° to—66°.
Muriate of Lime . 3 parts Snow 1	From—40° to—73°.

TABLE OF FREEZING MIXTURES CONTINUED.

Mixtures.	*Thermometer sinks.*
Dilut. sulphuric acid 10 parts Snow 8	From—68° to—91°.
Nitrate of ammonia 1 part Water 1	From 50° to 4°.
Nitrate of ammonia 1 part Carbonate of soda . 1 Water 1	From 50° to 3°.
Sulphate of soda . 6 parts Muriate of ammonia 4 Nitrate of potash . 2 Diluted Nitric acid 4	From 50° to 10°.
Sulphate of soda . 6 parts Nitrate of Ammonia 5 Diluted nitric acid . 4	From 50° to 14°.
Phosphate of soda 9 parts Diluted nitric acid . 4	From 50° to 12°.
Phosphate of soda 9 parts Nitrate of ammonia 6 Diluted nitric acid . 4	From 50° to 21°.
Sulphate of soda . 5 parts Diluted sulphuric acid 4	From 50° to 3°.

MANAGEMENT OF THE PRECEDING MIXTURES FOR PRODUCING COLD.

To produce the effects before stated, the salts must be reduced to powder, and contain their full quantity of water of crystallization. The vessel in which the freezing mixture is made should be very thin, and just large enough to hold it; and the materials should be mixed together as expeditiously as possible, taking care to stir the mixture at the same time with a rod of glass or wood.

In order to obtain the full effect, the materials ought to be first cooled to the temperature marked in *the table*, by introducing them into some of the other frigorific mixtures, and then mingling them together in a similar mixture. If, for instance, we wish to produce $= -46°$, the snow and diluted nitric acid ought to be cooled down to 0°, by putting the vessel which contains each of them into the fifth freezing mixture in the above table before they are mingled together. If a more intense cold be required, the materials to produce it are to be brought to the proper temperature by being previously placed in the second freezing mixture.

This process is to be continued till the required degree of cold has been procured.

SECT. IX.

CONVERSION OF SOLIDS AND FLUIDS INTO THE AERIFORM OR GASEOUS STATE.

We have seen before that in order to render solids fluid, a certain quantity of caloric is necessary, which combines with the body, and therefore cannot be measured by the thermometer; we shall now endeavour to prove, that the same holds good in respect to the conversion of solids or fluids into the vaporous or gaseous state.

CONVERSION OF SOLIDS INTO THE GASEOUS STATE.

Experiment I.

Take a small quantity of carbonate of ammonia, introduce it into a retort, the neck of which is directed under a cylinder filled with mercury and inverted in a basin of the same fluid. On applying heat to the body of the retort, the carbonate of ammonia will be volatilized, it will expel the mercury out of the cylinder, and become an invisible gas, and would remain so, if its temperature was not lowered.

The same is the case with benzoic acid, camphor, and various other substances.

SECT. X.

CONVERSION OF FLUIDS INTO THE GASEOUS STATE.

All fluids may, by the application of heat, be converted into an aeriform elastic state.

When we consider water in a boiling state, we find that this fluid, when examined by the thermometer, is not hotter after boiling several hours than when it began to boil, though to maintain it boiling a brisk fire must necessarily, be kept up. What then, we may ask, becomes of the wasted caloric? It is not perceptible in the water, nor is it manifested by the steam; for the steam, if not compressed, upon examination, is found not to be hotter than boiling water. The caloric is therefore absorbed by the steam; and although what is so absorbed is absolutely necessary for the conversion of water into the form of steam, it does not increase its temperature, and is therefore not appreciable by the thermometer.

This conclusion is further strengthened by the heat given out by steam on its being condensed by cold. This is particularly manifested in the condensation of this fluid in the process of distilling, where, upon examining the

refrigeratory, it will be found that a much greater quantity of caloric is communicated to it than could possibly have been transmitted by the coloric which was sensibly acting before the condensation. This may be easily ascertained by observing the quantity of caloric communicated to the water in the refrigeratory of a still, by any given quantity of liquor that passes over it.

1. *The boiling points of different fluids are influenced by atmospheric pressure.*

The boiling point, or the conversion of fluids into gases or vapours, always takes place at certain temperatures, which is different in different fluids, provided the pressure of the atmosphere be the same.

EXPERIMENT I.

Put any quantity of sulphuric ether into a florence flask, suspend a thermometer in it, and hold the flask over an Argand's lamp; the ether will immediately begin to boil, and the thermometer will indicate 98° if the ether has been highly rectified.

EXPERIMENT II.

If highly rectified ardent spirit is heated in a similar manner, the thermometer will rise to 176°, and there remain stationary.

EXPERIMENT III.

If water is substituted, it will rise to 212°.

EXPERIMENT IV.

If strong nitrous acid of commerce be made use of, it will be found to boil at 248°; sulphuric acid at 546°; and mercury and linseed-oil at 600°, &c.

2. *The boiling point of fluids is retarded by pressure.*

Mr. Watt heated water under a strong pressure to 400°. Yet still, when the pressure was removed, only part of the water was converted into vapour; and the temperature of this vapour, as well as that of the remaining fluid,

was no more than 212°. There were therefore 188° of caloric suddenly lost. This caloric was carried off by the steam. Now as only about $\frac{1}{5}$ of the water was converted into steam, that steam must contain not only its own 188° but also the 188° lost by each of the other four parts; that is to say, it must contain 188° × 5, or about 940°. Steam, therefore, is water combined with at least 940° of caloric, the presence of which is not indicated by the thermometer.

3. *When pressure is removed from the surface of bodies their conversion into the gaseous state is greatly facilitated, or their boiling point is lowered.*

In proof of this the following experiments may serve.

EXPERIMENT I.

Let a small bottle be filled with highly rectified sulphuric ether, and a piece of wetted bladder be tied over its orifice around its neck. Transfer it under the receiver of an air-pump, and take away the superincumbent pressure of the air in the receiver. When the exhaustion is complete, pierce the bladder by means of a pointed sliding wire, passing through a collar of leather which covers the upper opening of the receiver. Having done this, the ether will instantly begin to boil, and become converted into an invisible gaseous fluid.

EXPERIMENT II.

Take a small retort or Florence flask, fill it one half or less with water, and make it boil over a lamp: when kept briskly boiling for about five minutes, cork the mouth of the retort as expeditiously as possible, and remove it from the lamp.

The water, on being removed from the source of heat, will keep boiling for a few minutes; and when the ebullition begins to slacken, it may be renewed by dipping the retort into cold water.

The water during boiling becomes converted into vapour: this vapour expels the air of the vessel, and occupies its place: on diminishing the heat, it condenses; when

the retort is stopped, a partial vacuum is formed, the pressure becomes diminished, and a less degree of heat is sufficient to cause an ebullition.

For the same reason, water may be made to boil under the exhausted receiver at 94° Fahr. or even at a much lower degree; alcohol at 56°, and ether at — 20°.

On the conversion of fluids into gases is founded the following experiment:

Experiment III.

To freeze water by means of sulphuric ether.

Take a thin glass tube, four or five inches long and about two or three eights of an inch in diameter, and a two ounce bottle, furnished with a capillary tube fitted to its neck. In order to make ice, pour a little water into the tube; taking care not to wet the outside, nor to leave it moist. Having done this, let a stream of sulphuric ether fall through the capillary tube upon that part of it containing the water, which by this means will be converted into ice in a few minutes; and this it will do even near a fire, or in the midst of summer.

If the glass tube containing the water be exposed to the brisk thorough air or free draught of an open windw, a large quantity of water may be frozen in a shorter time: and if a thin spiral wire be introduced previous to the congelation of the water, the ice will adhere to it, and may thus be drawn out conveniently.

A person might be easily frozen to death during very warm weather, by merely pouring upon his body for some time sulphuric ether, and keeping him exposed to a thorough draught of air.

ARTIFICIAL REFRIGERATION.

The cooling or refrigeration of rooms in the summer season by sprinkling them with water, becomes likewise obvious on this account.

The method of making ice artificially in the East Indies

Depends on the same principle. The ice makers at Benares dig pits in large open plains, the bottom of which

they strew with sugar canes, or dried stems of maize or Indian corn. Upon this bed they place a number of unglazed pans, made of so porous an earth that the water penetrates through their whole substance. These pans are filled towards evening, in the winter season, with water that has boiled, and left in that situation till morning, when more or less ice is found in them, according to the temperature of the air; there being more formed in dry and warm weather than in that which is cloudy, though it may be colder to the human body.

Every thing in this process is calculated to produce cold by evaporation; the beds on which the pans are placed suffer the air to have a free passage to their bottoms; and the pans constantly oozing out water to their external surface, are cooled by the evaporation of it.

In Spain they use a kind of earthen jars called buxaros, which are only half-baked; the earth of which is so porous, that the outside is kept moist by the water which filters through it, and though placed in the sun, the water in the jar becomes as cold as ice.*

It is a common practice in China to cool wine or other liquors by wrapping the bottle in a wet cloth, and hanging it up in the sun. The water in the cloth becomes converted into vapour, and thus cold is produced.

The blacks in Senegambia have a similar method of cooling water, by filling tanned leather bags with it, which they hang up in the sun; the water oozes more or less through the leather, so as to keep the outward surface wet, which, by its quick and continued evaporation, cools the water remarkably.

The winds on the borders of the Persian Gulph are often so scorching, that travellers are suddenly suffocated unless they cover their heads with a wet cloth; if this be too wet they immediately feel an intolerable cold, which would prove fatal if the moisture was not speedily dissipated by the heat.

If a cold vessel is brought into a warm room, particularly where many people are assembled, the outside of it will soon become covered with a sort of dew.

Before some changes of weather the stone pavements,

* Twiss's Travels through Portugal and Spain. Similar jars are now made in this country.

the walls of a house, the balustrades of staircases, and other solid objects, feel clammy and damp.

In frosty nights, when the air abroad is colder than the air within, the dampness of this air, for the same reason, settles on the glass panes of the windows, and is there frozen into curious and beautiful figures.

Thus *fogs* and *dews* take place, and in the higher regions *clouds* are formed from the condensed vapour. The still greater condensation produces *mists* and *rain*.

SECT. XI.

CAPACITY OF BODIES FOR CONTAINING HEAT.

The property which different bodies possess of containing at the same temperature, and in equal quantities, either of mass or bulk, unequal quantities of heat, is called their capacity for heat. The capacities of bodies for heat are therefore considered as great or small in the ratio as their temperatures are either raised or lowered by the addition or diminished by the deprivation of equal quantities of heat.

In homogeneous bodies the quantities of caloric which they contain are in the ratio of their temperature and quantity of mass; for instance, when equal quantities of water, oil, or mercury, of unequal temperatures, are mingled together, the temperature of the whole will be the *arithmetical* mean between the temperatures of the two quantities that had been mixed together. It is a self-evident truth that this should be the case; for the particles of different portions of the same substance being alike, their effects must be equal. For instance,

Experiment I.

Mix a pound of water at 172° with a pound at 32°, half the excess of heat in the hot water will quit it, to go over into the colder portion: thus the hot water will be cooled 70°, and the cold will receive 70° of temperature; therefore 172—70, or 32 + 70 = 102 will give the heat

of the mixture. To attain the arithmetical mean very exactly, several precautions however are necessary.*

When heterogeneous bodies of different temperatures are mixed together, the temperature produced is never the arithmetical mean of the two original temperatures.

In order to ascertain the comparative quantities of heat of different bodies, equal weights of them are mingled together; the experiments for this purpose being in general more easily executed than those by which they are compared from equal bulks.

Experiment II.

If one pound of mercury heated to 110° Fahr. be added to one pound of water of 44° the temperature of the blended fluids will not be changed to 77°, as it would be if the surplus of heat were divided among those fluids in the proportion of their quantities. It will be found on examination to be only 47°.

Experiment III.

On the contrary, if the pound of mercury be heated to 44° and the water to 110°, then, on stirring them together, the common temperature will be 107°.

Hence, if the quicksilver loses by this distribution 63° of caloric, an equal weight of water gains only 3° from this loss of 63° of heat. And on the contrary, if the water loses 3° the mercury gains 63°.

When instead of comparing the quantities of caloric which equal *weights* of different bodies contain, we compare the quantities in equal *volumes*, we still find that the same difference takes place. Thus it is found by experiment, that the quantity of caloric necessary to raise the temperature of a given volume of water any number of degrees is to that necessary to raise an equal volume of mercury the same number of degrees as 2 to 1. This is therefore the proportion between the comparative quantities of caloric which these two bodies contain, estimated by their volumes; and similar differences exist with respect to every other kind of matter.

* Crawford on Animal Heat, p. 95, &c.

From the nature of the experiments by which the quantities of caloric which bodies contain are ascertained, it is evident that we discover merely the *comparative*, not the *absolute*, quantities. Hence water has been chosen as a standard, to which other bodies may be referred: its capacity is stated as the arbitrary term of 1000, and with this the capacities of other bodies are compared.

It need not be told that pains have been taken to estimate on these experiments that portion of heat which diffuses itself into the air, or into the vessels where the mercury and water are blended together. As, however, such valuations cannot be made with complete accuracy, the numbers stated above are only an approximation to truth.

SECT. XII.

RADIATION OF CALORIC.

CALORIC is thrown off or radiates from heated bodies in right lines, and moves through space with inconceivable velocity. It is retarded in its passage by atmospheric air, by colourless fluids, glass, and other transparent bodies.

For if a glass mirror be placed before a fire, the mirror transmits the rays of light, but not the rays of heat.

If a plate of glass, talc, or glass vessel filled with water, be suddenly interposed between the fire and the eye, the rays of light pass through it, but the rays of caloric are considerably retarded in its passage; for no heat is perceived until the interposed substance is saturated with heat, or has reached its *maximum*. It then ceases to intercept the rays of caloric, and allows them to pass as freely as the rays of light.

It has been lately shown by Dr. Herschel that the rays of caloric are refrangible, but less so than the rays of light; and the same philosopher has also proved by experiment, that it is not only the rays of caloric emitted by the sun which are refrangible, but likewise the rays emitted by common fires, by candles, by heated iron, and even by hot water.

Whether the rays of caloric are differently refracted in different mediums has not yet been ascertained. We

are certain, however, that they are refracted by all transparent bodies which have been employed as burning glasses. The rays of caloric are also reflected by polished surfaces, in the same manner as the rays of light.

This was long ago noticed by Lambert, Saussure, Scheele, Pictet, and lately by Dr. Herschel.

Professor Pictet placed two concave metallic mirrors opposite to each other, at the distance of about twelve feet. When a hot body, an iron bullet for instance, was placed in the focus of the one, and a mercurial thermometer in that of the other, a substance radiated from the bullet: it passed with incalculable velocity through the air, it was reflected from the mirrors, it became concentrated, and influenced the thermometer placed in the focus according to the degree of its concentration.

An iron ball two inches in diameter, heated so that it was not luminous in the dark, raised the thermometer not less than ten and a half degrees of Reaumur's scale, in six minutes.

A lighted candle occasioned a rise in the thermometer nearly the same.

A Florence flask containing two ounces and three drachms of boiling water raised Fahrenheit's thermometer three degrees. He blackened the bulb of his thermometer, and found that it was more speedily influenced by the radiation than before, and that it rose to a greater height.

M. Pictet discovered another very singular fact; viz. the *apparent radiation of cold.* When, instead of a heated body, a Florence flask full of ice or snow is placed in the focus of one of the mirrors, the thermometer placed in the focus of the other immediately descends, and ascends again whenever the cold body is removed.

This phenomenon may be explained on the supposition that from every body at every temperature caloric radiates, but in less quantity as the temperature is low; so that in the above experiment, the thermometer gives out more caloric by radiation than it receives from the body in the opposite focus, and therefore its temperature is lowered. Or as Pictet has supposed, when a number of bodies near to each other have the same temperature, there is no radiation of caloric, because in all of them it exists in a state of equal tension; but as soon as a body at an inferior

temperature is introduced, the balance of tension is broken, and caloric begins to radiate from all of them till the temperature of that body is raised to an equality with theirs. In the above experiment, therefore, the placing the snow or ice in the focus of the mirror causes the radiation of caloric *from* the thermometer, and hence the diminution of temperature which it suffers.

These experiments have been lately repeated by Dr. Young and Professor Davy, at the Theatre of the Royal Institution. These gentlemen inflamed phosphorus by reflected caloric, and proved that the heat thus excited was very sensible to the organs of feeling.

Mr. Leslie* has lately made a number of experiments on this subject, which are highly interesting. He used a variety of reflectors, carefully constructed of block-tin, and chiefly of the elliptical form. Sometimes he found the parabolic curvature convenient, especially when the reflection was made at considerable distances. The heat was given out from cubical boxes of plain and polished tin, with an orifice at the top, through which water of various temperatures was introduced, and a common mercurial thermometer occasionally placed in that fluid, to note the progress of its cooling. When the radiation of cold was to be tried, the canisters were filled with ice or snow. The differential thermometer being placed so that the ball containing the red liquor was in the focus of the speculum, and the canister being filled with boiling water the red liquor rose to a certain height, and then began to fall in proportion as the water cooled. A similar effect, though in the contrary direction, was produced by a canister filled with ice; and, in every case, the motion of the red liquor, above or below the point of equilibrium, was exactly proportional to the difference between the temperatures of the canister and the surrounding air.

If different substances were applied to the canister while giving out heat, the degree of its emission suffered very singular changes. If one side of the canister was coated with lamp-black, another with writing paper, a third with crown glass, and the fourth left bare, or covered with tin-foil—the differential thermometer rose to 100, 98, 90, and 12 respectively, when these four sides were exposed to the speculum in succession. The metal surface, then,

* Leslie on Heat.

gave out heat about eight times less copiously than the other three substances. By coating the focal ball of the differential thermometer with tin-foil, it was found to receive about five times less heat from any side of the canister than when it was exposed bare in the focus; and by coating the surface of a concave glass mirror, first with black pigment, then with tin-foil, and lastly exposing it bare to the heating body, it was found that the glass reflected very little heat, the pigment none at all, and the tin-foil ten times more than the glass. The metallic surface, then, has about five times less power of absorbing heat, eight times less power of emitting it, and ten times greater power of reflecting it, than the glass.

If between the canister and the reflector was placed a frame, over which were stretched, successively, tin-foil, glass and paper, the communication of heat or cold was altogether stopped by the first; at least so little passes, that the differential thermometer was not sensibly affected, while the glass only stopped four-fifths, and the paper not so much. The metallic screen, too, produced this effect, however near the canister it was placed, provided the separation was only sensible. The other two substances interrupted the communication more and more the nearer they were placed to the canister, but always permitted a large portion of the heat or cold to pass. If, instead of one screen, or a screen composed of only one substance, a combination of these was interposed, a very remarkable illustration of the general fact was obtained. The combinations used by Mr. Leslie were, plates of glass, coated with tin-foil on one side, and plates of tin, coated in like manner with lamp-black. These he either placed in contact, so that their similar sides touched; or at a distance from each other, with their similar sides facing. He denominates the combination of glass and tin-foil the *experimentum crucis*. We conceive that of the tin-foil and lamp-black better entitled to this appellation.

Experiment I.

Cause two sheets of tin about ten inches square to be hammered quite flat and smooth, and paint one side of each with a thin coat of lamp-black. Arrange the apparatus as usual, and, having joined together the tin-plates with their clear surfaces touching, fix them to a vertical frame: the liquor of the differential thermometer will rise

23 degrees. Invert the position of the plates, so that the blackened sides come into contact; it will now sink down to zero. Remove either of the plates, and the liquor will again mount near four degrees. It is truly pleasing, says Mr. Leslie, to witness this varied spectacle, where the changes succeed each other as if performed by the fancied operation of magic. But those transitions, and even the measures of the diversified effects, are the necessary results of the principles already established. Compare the case where both the external surfaces of the screen are metallic with that in which they are covered with pigment. On the one side it receives five times less heat, and this heat is propagated with eight times less energy from the other. By the joint influence of those circumstances, therefore, its effect is 40 times less; which corresponds to about half a degree, a quantity scarcely distinguishable. When the screen consists only of a single plate blackened on the one side, the diminished effect is a mean between the receptive and the projecting powers, or $6\frac{1}{2}$ times smaller than where both surfaces are painted. This enfeebled impression is consequently equal to about four degrees.

The experimental inquiries of Mr. Leslie, which were directed particularly to the radiation of heat, its connection with the spaces through which it is propagated, the direction in which it moves, the projecting power of the heated body, and connection which subsists between it and the nature of the projecting surface, are highly important.

The canister being placed successively at different distances from the reflector, the effects of its removal, upon the differential thermometer in the focus, were noted; and an allowance was made for the changes in the focal length. It was found, in general, that the total corrected effects were inversely as the distances of the canister. This obstruction evidently cannot arise from the loss of heat in the atmosphere; for that cause would produce a diminution in a much more rapid series. To prove that the irregularity of the reflecting surface has no share in the phenomenon, Mr. Leslie shews that a concave glass speculum reflects the heat of a charcoal fire with an energy inversely as its distance. The diminution, then, can only

be owing to an imperfect reflection; and this was well demonstrated, by increasing the size of the canister, in such a proportion to its increased distance from the reflector, that it always subtended an equal angle there. Making the same correction as before, for the variation of focal length, the total effect of the removal upon the differential thermometer was found to be nothing more than might fairly be ascribed to the inaccuracy unavoidable in such delicate experiments. Hence the capital inference is drawn, that the impulses, by which heat and cold are propagated between distant objects, do not suffer any sensible diminution of strength from the length of their progress through the atmosphere.

A very remarkable aberration is observed to take place in the reflection of heat. When the flame of a taper is withdrawn above two inches from the axis of the reflector, its image vanishes entirely from the focal ball of the differential thermometer. But the heated canister may be removed seven inches from the axis, before its impression on the instrument ceases to be distinguishable. Mr. Leslie gives us no computation of the extent of this penumbra of heat (if the expression may be used) he only explains the law by which the lateral motion of the heated body, from the reflector's axis, diminishes the total effect of the reflection upon the thermometer. The distance of the canister being proportioned to the series 1, 2, 3—7, the rise of the thermometer is as the powers of $\frac{5}{6}$, whose exponents are the triangular numbers, 1, 3, &c. He also finds, by experiment, what he pretends is also a deduction from the aberration just now described, that the maximum of the effect produced by reflection is not in the focus, but nearer the speculum. His experiment is quite conclusive. The thermometer being at 58° in the optical focus, it rose to 80° half an inch nearer the reflector; and, half an inch beyond the focus, fell to 25°. The heat is therefore more diffused over equal spaces beyond the focus than between the focus and reflector.

If the side of the canister is turned gradually round, while its axis remains fixed in the axis of the reflector, the thermometer is less and less affected, as the radiating surface is more inclined from the perpendicular. Nothing can be simpler than the method adopted by Mr. Leslie

for ascertaining the law of this diminution. He placed a sliding screen between the canister and the reflector, and adjusted the slit so, that the radiating surface, at every part of its motion round its axis, subtended the same angle as the reflector. There was scarcely any effect produced upon the thermometer by the revolution of the canister. In like manner a cylindrical canister produces the same rise in the thermometer with a cubical one of an equal base and altitude; and from these, and other experiments founded upon the same principle, we may conclude, that the total action of a heated surface is equal to that of its orthographic projection, or proportional to the sine of its inclination.

Mr. Leslie having ascertained that bodies differ very widely in their power of projecting, absorbing, and reflecting heat, found that the *chemical qualities* of the heating surface have a considerable influence upon its projecting power; the effect of tin being 12, iron or steel operates as 15, mercury above 20. All oxydes acquire a greater action as they recede from the metallic state. Lead being as 19; when tarnished by exposure to the air, it becomes as 45, while minium is as 80. Sealing-wax and rosin are nearly equal to paper, and ice is as 85. The *polish* of the radiating surface diminishes its action, where that is not naturally great. The roughening of glass does not heighten its projecting power; but that of tin is doubled by covering it with furrows. This singular effect cannot be owing to the greater surface which the roughened metal exposes; for the increase of surface is precisely counterbalanced by the increase of obliquity; and, moreover, it is found that the addition of cross furrows, by striating the surface in the other direction, nearly destroys the effect of the first operation. The *thickness* of the radiating surface greatly affects its powers of action. A thin film of isinglass produces a radiation as 26; a thick one as 42: but when the thickness exceeds the thousandth part of an inch, any subsequent increase does not augment its action. Mr. Leslie thinks that the difference in projective power, which is observable in several of the cases above noticed, may be resolved into the variations of the bodies with respect to hardness and softness. He reasons this matter with his wonted inge-

nuity, and shows that the addition of moisture, and still more the addition of a mucilaginous substance, considerably augments the action of a surface painted black. The quality of *colour* is the last to which our attention is directed, and Mr. Leslie seems disposed to doubt whether it exerts any influence at all in modifying the projective and absorbent powers of bodies; a point which he conceives is incapable of strict solution, because a change of colour must always be attended with an alteration in the structure of the substance: and, rigorously speaking, this is no doubt true. But there is one mode of inducing a change of colour, by means of a change in the body's structure, which is known, and for which allowance may be made by our author's experiments; we allude to the scoriæ on the surface of metals, from slight oxydation. If the oxydation is found always to augment the metal's action, as different metals assume different hues in the beginning of the process, a comparison of several, in this respect, will enable us to estimate how far colour operates. Perhaps even the change induced upon the substance of vegetable tinctures, by weak, acidulous, and alkaline solutions, is so little proportionate to the alterations which their colours undergo in the mixture, that an approximation might be obtained from experiments with paper dyed in this manner.

Mr. Leslie repeated several branches of this inquiry, to ascertain the various *reflecting* powers of different surfaces. Those which absorbed and projected heat most copiously were, in general, found to reflect least, though by no means in a reciprocal proportion. Glass reflecting as 10, tin-foil reflected as 85, lead as 60, steel as 70; tin-foil shining with mercury as 50, and brass as 100. A tin reflector had its power reduced to one tenth, by being striated in one direction, although this operation did not at all change the limits of its focus. A coat of tallow reduced the powers of the reflector to one twelfth; a coat of olive oil to two fifths; a coat of isinglass to three tenths, but, as it dried and became thinner, only to seven tenths: a thin irridescent coating reduced the reflection only to four fifths. The general rule then holds good, that the reflecting powers of bodies bear some inverse ratio to their absorbent and projective powers; although

so many circumstances unite in modifying the proportion that we are unable, as yet, to express it by one universal law.

It is therefore evident that caloric is thrown off from bodies in rays, which are invisible, or incapable of exciting vision, but which are capable of exciting heat.

These invisible rays of caloric are propagated in right lines, with extreme velocity, and are capable of the laws of reflection and refraction.

The heating agency, however, is different in the different coloured rays of the prismatic spectrum. According to Dr. Herschel's experiments, it follows inversely the order of the refrangibility of the rays of light. The least refrangible possessing it in the greatest degree.

Sir Henry Englefield has lately made a series of experiments on the same subject, from which we learn that a thermometer having its ball blackened rose when placed in the *blue* ray of the prismatic spectrum in 3′ from 55° to 56° ; in the *green*, in 3′ from 54° to 58° ; in the *yellow* in 3′ from 56° to 62° ; in the *full red*, in $2\frac{1}{2}'$ from 56° to 72° ; in the *confines of the red*, in $2\frac{1}{2}'$ from 58° to $73\frac{1}{2}°$; and *quite out of the visible light*, in $2\frac{1}{2}'$ from 61° to 79°.

Between each of the observations, the thermometer was placed in the shade so long as to sink it below the heat to which it had risen in the preceding observation ; of course its rise above that point could only be the effect of the ray to which it was exposed. It was continued in the focus long after it had ceased to rise ; therefore the heats given are the greatest effects of the several rays on the thermometer in each observation. A thermometer placed constantly in the shade near the apparatus was found scarcely to vary during the experiments.

Sir Henry made other experiments with thermometers with naked balls, and with others whose balls were painted white ; for which we refer the reader to the interesting paper of the baronet,* from which the above experiments are transcribed.

The coloured rays emitted from the sun and combustible bodies, since they excite heat and vision, must consist of a mixture of heat-making rays and rays of light.

* Journals of the Royal Institution, No. x. p. 202.

And as the rays of heat and light accompany each other when emitted from luminous bodies, the velocity with which the rays of caloric move must be equal to that of light; and hence its particles must be equally minute. They differ however in this particular, that the rays of light produce the sensation of vision, and possess certain chemical properties, whilst in those of caloric the peculiar agency of heat resides.

LIGHT.

(SEE APPENDIX NO. 9.)

PART XI.

THE difference, in the day time, of what we perceive when our eyes are open and when our eyes are shut is produced by what is called *light*. The privation of light is called *darkness*.

It is this light which informs us of the presence of objects which are not near enough to touch our bodies, or which do not affect any of our other senses. Hence the blind must judge of the presence of the particular objects by the sound, or by the smell, or by the touch, &c. but not by means of light. In short, light does not sensibly affect any other part of our frame, besides the eyes.

The nature of light has occupied much of the attention of thinking men, and numerous opinions have been entertained concerning it. It has been sometimes considered as a distinct substance, at other times as a quality; sometimes as a cause, frequently as an effect: by some it has been considered as a compound, by others as a simple substance. Philosophers of the present day are not agreed as to the independent existence of light, or the cause by which we see.

This is not the place for discussing the respective merits of all the ingenious hypotheses which have been advanced concerning this subject: we shall assume the doctrine of those who admit the independent existence of light, not only because it is more generally received, but is also best calculated to explain its chemical properties.

SECT. I.

NATURE OF LIGHT IN GENERAL.

LIGHT is that which proceeds from any body producing the sensation of vision, or perception of other bodies, by depicting an image of external objects, on the retina of the eye. Hence it announces to animals the presence of the bodies which surround them, and enables them to distinguish these bodies into transparent, opaque, and coloured. These properties are so essentially connected with the presence of light, that bodies lose them in the dark, and become undistinguishable.

Light is regarded by philosophers as a substance consisting of a vast number of exceedingly small particles, which are actually projected from luminous bodies, and which probably never return again to the body from which they were remitted.

They have a determinate size; they are at a certain distance from each other; they move with a certain velocity, and have a certain momentum. They are universally expanded through space; they exert peculiar actions; and are obedient to the laws of attraction, and other properties of matter.

Several remarkable discoveries made in astronomy, and in other branches of natural philosophy, give us some ideas concerning the size, distance, velocity, &c. of the particles of light.

1. EXPLANATION OF CERTAIN TERMS OF LIGHT.

In order to facilitate the doctrine of light, we shall shortly explain a few terms made use of by philosophers when treating of it; namely:

A *ray of light* is an indefinitely small portion of light as it comes from a luminous body.

A *medium* is a body which affords a passage for the rays of light.

A *beam of light* is a body of parallel rays.

A *pencil of light*, or a pencil of rays of light, is a body of diverging or converging rays.

Converging rays are rays which tend to a common point.

Diverging rays are those which come from a point, and continually separate as they proceed.

The rays of light are *parallel*, when the lines which they describe are so.

The radiant point is the point from which diverging rays proceed.

The *focus* is the point to which the converging rays are directed.

2. SOURCES OF LIGHT.

Light is emitted from the sun, the fixed stars, and other luminous bodies. It is produced by percussion, during electrization, combustion, and in various other chemical processes.

Why the sun and stars are constantly emitting light, is a question which probably will for ever baffle human understanding; at any rate, it is not connected with chemistry.

The light emitted during combustion, or chemical action, exists previously, either combined with the combustible body or with the substance which supports the combustion. The light emitted during percussion and electrization, &c. is foreign to our subject.

SECT. II.

PHYSICAL PROPERTIES OF LIGHT.

1. VELOCITY OF LIGHT.

The velocity of light is much greater than that of sound; for the flash of a gun fired at a considerable distance is seen before the report is heard.

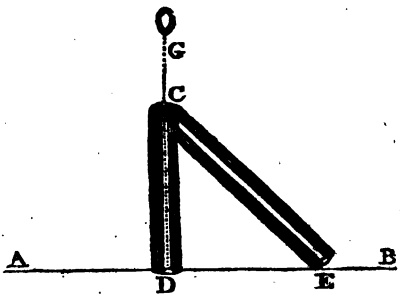
The clap of thunder is not heard till some time after the lightning has been seen, except the phenomena takes place at no great distance.

The motion of light is so very rapid, that in all common experiments it appears to be instantaneous. Its velocity cannot be measured between the tops of the most distant mountains that are visible from each other. Astronomers have, nevertheless, found that it *may* be measured when it moves between some of the heavenly bodies. For by the eclipses of Jupiter's satellites, it appears that it takes 8 minutes and 13 seconds in passing across the semidiameter of the earth's orbit. From these accurate investigations they have deduced that light moves at the astonishing rate of about 167,000 geographical miles in one second, or that it passes from the sun to the earth in little more than eight minutes; and nevertheless, according to geometricians, light, from its departure from the nearest of the fixed stars, which is, in truth, at least four hundred thousand times more remote than the sun, is near six years in its progress to our eyes; so that a star placed at that distance would be still visible for six years after its destruction, supposing that process to take place. How grand and sublime are the meditations suggested by this object on the immensity of space, the boundless extent of the universe, the vast number of globes which traverse through it, and the duration of time which they measure in their silent march!

The velocity of light was first noticed by Roemer, and afterwards determined and established by Dr. Bradley's ingenious theory on the aberration of the lights of the fixed stars. The principles on which this discovery is founded may be familiarly explained as follows:

Suppose a tube to be erected perpendicular to the horizon at a time when it rains, the drops falling perpendicularly down; and suppose the diameter of the tube to be such as to admit but one drop at a time; then it is plain, that if a drop of water enter the orifice of the tube it will fall to the bottom without touching its sides. But if the tube, without altering its perpendicularity, be moved along in the direction of the horizon, any drop that enters will strike against one of its sides, and none will pass clearly through while the motion continues, unless the upper end of the tube be also inclined towards the part to which its motion is directed.

Thus, if A B represent the horizon, C D the perpendicular tube, and G D the course of a drop of rain: then, if C D be moved towards A, while the drop is falling within the tube, it is evident that the inner surface of the tube, which is situated towards B, will be carried against the drop, and prevent its arriving at the bottom without touching. But if the inclined tube E C be moved with a similar motion to that of the drop from E to D, in the time that the drop moves from C to D, the lower orifice of the tube and the drop will be found at D at the same instant; and the velocity of the drop will be expressed by C D, and that of the tube by E D.



The same reasoning holds good, if instead of drops of rain we suppose particles of light, and a telescope instead of a tube. For to an observer, who through the tube C D views the vastly distant object G, if the motion of light be instantaneous, or infinitely swift, no finite motion of C D, its position being unaltered, can prevent its being visible; since, by the supposition, the light which enters at C will arrive at D before C D can have moved at all. But if light be propagated in time, and the observer be carried by a motion similar, as to acceleration, to that of light, the tube must be inclined to the ray in an angle, whose sine is to the sine of C E D, or the angle the tube makes with the line of the observer's motion, as the velocity of the observer is to the velocity of light. For in the triangle D C E, the sides D E and D C, which express these velocities, are as the sines of their opposite angles. Hence if the angle of the inclination of the tube to the ray of light, together with the velocity and direction of the observer's motion, be known, the velocity of light may be determined.

The velocity of light is uniform in the same medium, however it may be excited; either because the corpuscles

are emitted by a peculiar repulsive force, acting equally in all bodies and in all directions, and known only by this effect; or simply, because a homogeneous fluid propagates all impulses with a constant velocity.

2. MOMENTUM AND MAGNITUDE OF THE PARTICLES OF LIGHT.

The velocity of light being thus ascertained, we should be enabled to form some notion of the magnitude of the particles of light, if we were in possession of good observations on the effect of their momentum.

For example; it is found that a ball from a cannon at its first discharge flies with a velocity of about a mile in eight seconds, and would therefore arrive at the sun in thirty-two years, supposing it to move with unremitted celerity. Now light moves through that space in about eight minutes, which is two million times faster. But the forces with which bodies move are as their masses multiplied by their velocities: if, therefore, the particles of light were equal in mass to the two millionth part of a grain of sand, we should be no more able to endure their impulse than that of sand when shot point-blank from the mouth of a cannon.* How much less must therefore be the particles of light, which make no sensible impression upon so delicate an organ as the eye.

From some imperfect experiments made by throwing the focus of a concave mirror on the extremity of a very delicate beam, nicely suspended, by which means a slight motion was given to the beam, it was deduced that the light thus collected had a searchable momentum. Now from the weight of the beam, and from the motion which was communicated to it by the impulse of light (if that was the real cause of its motion) also from the above-mentioned velocity of light, it was calculated that the matter contained in the light which was thrown upon the end of the above-mentioned beam during one second of time, and which was collected from a reflecting surface of about four square feet, amounted to no more than one twelve hundred millionth part of a grain.†

* Nicholson's Introd. to Natural Philosophy, vol. I. p. 256.

† Priestley's History of Discoveries on Light, Vision, &c. Period VI. Sect. I. chap. iii.

3. LIGHT MOVES IN STRAIGHT LINES.

Whenever light passes through a space occupied by a medium of uniform density, it describes right lines in all directions. Because all undisturbed motion is rectilinear; or because, in a homogeneous and highly elastic medium, all undulations are transmitted rectilinearly.

It is well known that if a portion of a beam of light be intercepted by any body, the shadow of that body will be bounded by right lines, passing from the luminous body, and meeting the lines which terminate the opaque body.

Experiment I.

Darken a room into which the sun shines, and only admit the light by a small hole in the window-shutter; and place opposite to the hole a board or screen. If we look at the screen, we observe thereon a picture of all the exterior objects which are opposite to the hole in all their natural colours: these colours are faintly depicted; the images of the objects that are stationary, as houses, trees, &c. are likewise fixed or stationary in the picture; whilst the images of those that are in motion, as those of horses, carriages, &c. are seen to move. If we place our eye in this ray, we find that our eye, the light, and the hole are in one and the same straight line. Which is a clear proof that light is emitted in straight lines, by the luminous bodies.

It is equally obvious from light finding no passage through bent or crooked tubes.

4. REFLECTION OF LIGHT.

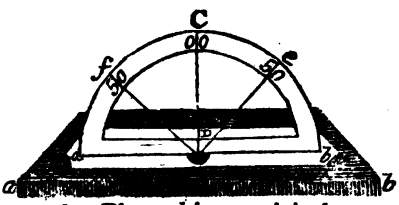
Another property of the rays of light is their *reflexibility*, or disposition of being turned back into the medium in which they moved with a certain obliquity, so that the light is driven back, without coming into contact with the matter which repels it.

The ray is then said to be *reflected*. The angle of reflection is always equal to the angle of incidence.

Experiment II.

To prove that the angle of reflection is equal to the angle of incidence.

There are several ways of measuring the angles of incidence and of reflection; but the following is one of the easiest:



Let *a b c* be a semicircle, divided into twice 90 degrees; *a b* represents the section of a flat reflector. Cover the surface of this reflector with paper, excepting a very small circular spot, as at *d*. Place this semicircle perpendicularly upon the reflector, and with its centre in the middle of the uncovered spot *d* of the reflector. This being done, fix a pin, or other small object, close to the edge of the semicircle, for instance, at *e*, the 50th degree; then move your eye along the side *a f c* of the semicircle, and you will perceive the object *e* reflected by the reflector *d* only when the eye is at *f*, viz. at the 50th degree of the quadrant *a f c*; whence it becomes evident that the angle of reflection *c d f* is equal to the angle of incidence *f d c*.

When a ray of light falls upon a polished medium, for instance, a plate of glass, or mirror with a certain obliquity, it does not enter the glass at all, but is reflected when it approaches its surface. When a ray of light enters other transparent *media*, it continues to move on till it comes to the opposite surface; but then, instead of passing through, it bends, and passes out again at the same surface at which it entered, just as a ball would do if made to strike obliquely against a floor.

Experiment III.

Let a beam of solar light pass into a darkened room through a hole in the window-shutter; at that part of the floor where the beam of light falls place a looking-glass,

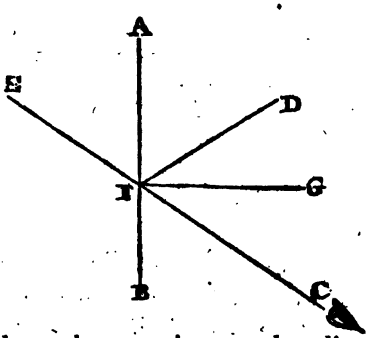
and then throw some hair-powder into the air, in order to render the beam of light more visible.

We shall then see that the beam is reflected back into the air, and that the inclination of the reflected beam is exactly the same as that of the incidental one.

The common experiment of children casting the light of the sun, by means of a looking glass, into various distant places, also illustrates this property.

If we direct our eyes towards certain polished surfaces, we frequently see in them the appearances of objects which are situated in places quite different from those in which we see them.

Thus: an eye at C, directed towards the flat and polished surface of which A B is the section, will perceive the exact figure, colour, &c. of a body which actually stands at D, but which will appear as if it stood at E; it is therefore evident that the light which proceeds from D falls upon the surface A B, and thence it comes into another direction, F C, to the eye at C. Now the surface A, B, which thus sends back the light, is called the *reflected light*; whereas the light from the object D, to the reflecting surface, is called the *incident light*.



The angle which the incident light makes with the perpendicular to the reflecting surface at the point of incidence, viz. the angle D F G, is called *the angle of incidence*.

The angle which the reflected light makes with the same perpendicular, viz. the angle C F G, is called the *angle of refraction*. But some authors call the angle D F A the angle of incidence, and the angle C F B, the angle of refraction.

5. INFLECTION OF LIGHT.

When a ray of light passes within a certain distance of the surface of a body, parallel to which it is moving, it is

attracted, or bent *towards* it, so as to form apparently a rectilinear angle at that place. This bending or inflection of the rays of light, by passing not through, but near, the surface, is caused by an attractive power to which light is obedient. It is called therefore the inflection of light. It has also been called *diffraction.*

Experiment I.

Admit a beam of light into a dark room, through a round hole in the window-shutter, and place at the spot on the floor where it falls a sheet of paper; the rays of light will there form a round luminous spot. But if we bring two penknives, with their edges towards each other, on opposite sides of the hole, and make them approach each other gradually, the luminous spot will dilate itself on the sides of the knives; indicating that those rays which are nearest the edges of the knives have been drawn from their former direction towards the knives. This property of light is called *inflection.* The edge of any other thin plate of metal produces the same effect.

Experiment II.

If we let a beam of light pass into a dark room through a narrow slit made in a window shutter, not above $\frac{1}{100}$ part of an inch broad, the beam of light will be split into two, and leave a dark space in the middle; it will therefore be attracted by both sides of the slit.

Experiment III.

The shadow of a small body, as a hair, a thread, &c. placed in a beam of the sun's light, will be much broader than it ought to be if the rays of light passed by these bodies in right lines, or without being attracted by them.

For example: a hair whose breadth was the 280th part of an inch, being held in this light, at the distance of about twelve feet from a hole of the breadth of the 42d part of an inch, did cast a shadow which, at the distance of four inches from the hair, was the 60th part of an inch broad, that is, above four times broader than the hair; and at the distance of ten feet was the eighth part of an inch broad, that is, 85 times broader.

The phenomena which relate to the inflection of light, not appearing to be reducible to one general principle, were particularly examined under a considerable variety of circumstances by Sir Isaac Newton: yet his observations were not quite correct, nor was his hypothetical explanation very plausible. Subsequent experiments and observations have reduced the phenomena of inflection to a single principle, namely, to the attraction of bodies towards light; which attraction becomes conspicuous when the rays of light pass within a certain distance of their surfaces. Besides their being bent, the rays of light are likewise separated into colours by the vicinity of bodies, and this produces the singular phenomena of the coloured fringes that accompany the inflection.

6. REFRACTION OF LIGHT.

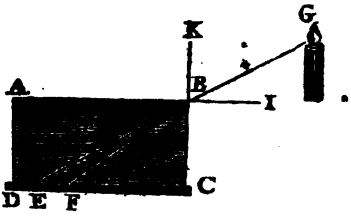
When a ray of light passes through the same medium, or when it passes perpendicularly from one medium into another, it continues to move on, without changing its direction. But the case is different when it passes obliquely from one medium into another of a *different density*; it is then bent from its first direction, and assumes a new one; it is said to be *refracted*. When it passes into a denser medium it is refracted *towards* the perpendicular; but when it passes into a rarer medium it is refracted *from* the perpendicular.

The denser the medium the more the rays are bent, and approach to a perpendicular let fall upon its surface.

This, however, must always be understood of the rays which fall obliquely upon these *media*; for those rays which fall perpendicularly do not suffer any deviation: *refraction only takes place when the rays fall obliquely*, and is so much greater as their angle of incidence is more oblique. After having taken the new direction, the ray again proceeds invariably in a straight line, till it meets with a different medium, when it is again turned out of its course. On this account it is that objects seen under water appear out of their true place.

Experiment I.

Let a lighted candle be placed on the side of a vessel full of water A B C D, so as to cast a shadow on the side of the vessel upon the bottom: the edge of the shadow does not come to E, so as to form a straight line E B G, but will be found somewhere else, as at F, and F B G will form an angle at the surface of the water; which proves beyond a doubt that the light which proceeds from the candle is refracted, viz. bent at the surface of the water. This will become equally obvious from the following experiments:



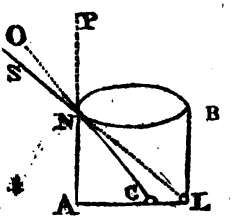
Experiment II.

Take an empty basin, and on the bottom fix marks at a small distance from each other; then take it into a dark room, and let in a ray of light: where this ray falls upon the floor, place the basin, so that its marked diameter may point from the window, and so that the beam of light may fall on the mark most distant from the window. Having done this, when the basin is filled with water the beam which before fell upon the most distant mark will now, by the refractive power of the water, be turned out of its straight course, and will fall two, three, or more marks nearer to the centre of the basin.

This may be more clearly proved in the following manner;

Experiment III.

Let a small bright object be laid upon the bottom of a cylindrical vessel N B A L at C, so that a ray passing in a right line from the remote edge of the object to the eye at S will be intercepted by the edge of the vessel, or that the first ray which is not intercepted passes in the direction O N C above the eye. While the eye continues in the same situation, if the vessel be filled with water the object will become visible, that is, the ray which passed from the remote edge of the ob-



ject in a right line C N O by the vessel on entering the air is refracted into the direction N S towards the eye, or from the perpendicular P N A.

It is upon the reflection and refraction of light that the whole science of optics principally depends; for if the rays of light were neither reflexible nor refrangible we should be deprived of telescopes, microscopes, spectacles, and a number of other optical instruments.

SECT. III.

ANALYSIS OF LIGHT BY THE PRISM.

EVERY ray of light consists of seven parts; the first of these seven parts of the ray excites upon our organs of sight the sensation which we call *red*, the second excites the sensation called *orange*, the third *yellow*, the fourth *green*, the fifth *blue*, the sixth *indigo*, and the seventh *violet*.

None of these seven parts of a ray of light can be further decomposed; they always produce the same colour, on which account they are called original or primitive colours.

EXPERIMENT I.

To prove that light consists of these primitive colours, let a ray of it fall through a hole in a window-shutter into a darkened room; and place a glass prism parallel to the horizon with its axis perpendicular, so as to receive the beam of light. On turning the prism slowly about its axis, we perceive that the refracted light on the opposite wall first descends and then ascends between the ascent and descent; that is, where the *spectrum* is stationary the prism is to be fixed.

The beam of light now passes into the prism, and is there refracted into its primitive rays, *viz.* the lower extremity of the *spectrum* is red, above this is placed the

orange, afterwards the yellow, then the green, the blue, the indigo, and lastly the violet, which is placed in the upper part of the image.

The instance of the separation of the primary colours of light which seems most remarkable is that of the rainbow. It is formed in general by the reflection of the rays of the sun's light, from the drops of falling rain; though frequently it appears amongst the waves of the sea, whose heads or tops are blown by the wind into small drops; and it is sometimes seen on the ground, when the sun shines, in a very thick dew. Cascades and fountains whose waters are, in their fall, divided into drops, exhibit rain-bows to a spectator, if properly situated during the time of the sun's shining; and water blown violently from the mouth of an observer whose back is turned towards the sun never fails to produce the same phenomenon.

This appearance is also seen by moon-light, though seldom vivid enough to render the colours distinguishable; and the artificial rainbow may be produced even by candle-light, on the water which is ejected by a small fountain or *jet d'eau:* all these are of the same nature as the analysis of light by the prisms.

The colours observable on soap-bubbles, and the halos which sometimes surround the moon, are also referrible to the refrangibility of the rays of light.

Various methods have been tried for the purpose of rendering the colours of the prismatic spectrum distinct or unmixed with each other, but none as yet has been attended with complete success: the following method seems to be the best approximation.

Experiment II.

Let the light of the sun pass through a hole of the $\frac{1}{10}$ of an inch into a dark room; and placing a screen at a little distance (for instance, 6 inches) within the room, let the middlemost part of that light pass through a smaller hole in the screen; the object of which is to prevent, in great measure, the indefinite light, or penumbra on the sides of the prismatic spectrum. Let that light fall perpendicularly upon a convex lens, at the distance of about 10 feet, by which means an image well defined of the

sun will be formed upon a screen placed at a proper distance from the lens: but if a prism be placed close to the lens, so that the light, after having passed through the lens, may pass through and be refracted by the prism, then a coloured spectrum well defined will be formed upon the screen.

If small bodies be placed in the different colours of the prismatic spectrum, they will appear of the same colour, red in the red light, green in the green light, &c.

The decomposition effected by means of the prism has therefore been called an analysis of light.

These coloured rays differ from each other in reflexibility, refrangibility, and inflexibility. The red is the most refrangible, the violet the least; the others are refrangible in the following order, namely, orange, yellow, green, blue, indigo, and violet.

Newton ascertained by actual measurement, that if the whole of the spectrum be divided into 360 parts, then the red will occupy 45 of these parts, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80.

Dr. Herschel has lately proved* that the rays of light differ in their power of illuminating objects. The rays towards the middle of the spectrum possess the greatest illuminating powers, and those at the extremity the least; the illuminating power of the rays gradually diminishes from the middle of the spectrum towards its extremities.

Experiment III.

That the rays of light differ in their illuminating power may be evinced by letting equal portions of each of them fall on a minute object; a printed page, for instance, which will not be seen distinctly at the same distance when illuminated by each. We must stand nearer the object when it is illuminated by the violet; we see distinctly at a somewhat greater distance when the object is illuminated by the indigo ray, at a greater when by the blue, at a still greater when by the deep green, and at the greatest of all when by the lightest green, or deepest yellow: we must stand nearer when the object is enlightened by the orange ray, and still nearer when by the red.

* Philosoph. Trans. 1800, p. 255.

It has been supposed that three of the prismatic colours, the red, yellow, and blue, were simple; and that the other four were formed each of the two contiguous ones; that is, the orange from the red and yellow, the green from the yellow and blue, the indigo from the blue and violet, and the violet from the indigo and red: but this supposition has not been satisfactorily proved.

SECT. IV.

THEORY OF COLOURS.

LANGUAGE being invented chiefly for the expression of ordinary events that do not require any great precision, it very frequently happens that the same word is used to denote very different things. It is proper to remark, that the word colour is thus used. If the word be used to denote the sensation or idea excited in the mind, it is sufficiently obvious that it cannot be sufficiently used to denote that attribute by which bodies are able, by reflecting the rays of light, to produce the sensation; and still less ought it to be used to imply that quality the various kinds of light possess of producing the sensation when separated from each other, either by reflection from bodies or otherwise. It may, however, be allowed to use the terms coloured rays, or coloured bodies; though the sensation of colour, the specific properties of the rays and of the reflecting bodies, are undoubtedly things very different from each other.

Having, therefore, so far considered the nature and effects of light, and seen that it is subject, like other matters, to the laws of attraction and repulsion, and that it may be analysed by means of the prism into several rays of different tints, we shall now endeavour to prove, that from the nature of these different tints arises that variety of shades which paints the face of nature.

Hence it is, that whatever pleasure we derive from the beauty of colouring is owing to the different refrangibility of light, each object sending back to our eyes those rays which the peculiar structure of its surface is best adapted

to reflect. In this sense, the blushing beauties of the rose, and the modest blue of the violet, may be considered as not in the objects themselves, but in the light that adorns them in those robes.

The colours of all natural bodies depend on this refrangibility of light; they may be considered as prisms, which decompose or rather divide the light. Some reflect the rays without producing any change, and these are *white*; others absorb them all, and are therefore *black*. The greater or less affinity of the several rays with various bodies is no doubt the cause that when a pencil of light falls upon a body some rays enter into it, whilst others are reflected; and it is this which affords the diversity of colours and the prodigious variety of shades under which bodies appear to our eyes: and thus are formed the pellucid stream, the green sea, the white froth, the dark pool, the azure sky, the varying colours of the pigeon's neck, the opal, the mother-of-pearl, the silk called changeable, &c. and hence the white colour of the European, the copper colour of the American, and black colour of the Negro.

The changes of colours which are produced by mixtures, by boiling, heating, pounding, &c. are so common and so remarkable, as to come within every body's notice. The following chemical production of colours will, perhaps, not be unacceptable to some readers.

Experiment I.

Production of various colours by the mere mixture of colourless fluids.

For this purpose the following articles are necessary.

No. 1. A solution of acetite of lead, prepared by dissolving two drams of acetite of lead in twelve ounces of distilled water, and afterwards filtering the solution.

2. A solution of carbonate of potash, obtained by dissolving three ounces of carbonate of potash in twelve of water, and proceeding as before.

3. A solution of corrosive muriate of mercury, consisting of twenty grains of corrosive muriate of mercury dissolved in twelve ounces of water.

4. A solution of sulphate of iron, produced by dissolving two ounces of sulphate of iron in twelve of water.

5. Acidulous solution of sulphate of iron, composed of an ounce of sulphate of iron and twelve of water, mixed with an ounce of the next solution, No. 6.

6. One ounce of sulphuric acid, mingled with twelve of water.

7. One dram of crystallized acetite of copper, dissolved in twelve ounces of water, with the addition of one dram of nitric acid.

8. Concentrated liquid ammonia.

9. Sulphureous acid.

10. Tincture of roses, prepared by infusing red rose leaves in sulphureous acid.

11. Tincture of red-cabbage leaves, prepared in the same manner.

12. Tincture of galls, obtained by digesting half an ounce of gall-nuts in twelve ounces of water, and adding one dram of nitric acid to the filtered solution.

13. Diluted solution of prussiate of potash.

14. A solution of nitrate of mercury, obtained by dissolving one dram of mercury in half an ounce of moderately strong nitric acid, mingling the solution with an ounce of water.

By merely mixing these colourless fluids, the following tints are produced.

Milk-white...Mix three parts of No. 1 with one of No. 2.

Yellow....Four parts of No. 14 and one of No. 2.

Orange....Four parts of No. 3 with one of No. 2. If No. 6 be added, the orange colour disappears, and the whole returns to its limpid state.

Carmine....A few drops of No. 6 with No. 10. This colour disappears on adding No. 9.

Blood-red....A few drops of No. 6 with No. 11. This liquid becomes again colourless on adding No. 9.

Grass-green....Three parts of No. 10 with one of No. 1. On adding No. 6, the mixture turns to red; a few drops of No. 9 destroy this colour, and the fluid returns to its former limpid state.

Light-green....Three parts of No. 14 with one of No. 1.

Ultramarine-blue....Three parts of No. 7 with one of No. 8. It becomes again colourless by adding No. 6.

Dark-blue....Three parts of No. 11 with one of No. 2, the addition of No. 6 changes it to ruby-red.

Prussian-blue....By mixing equal quantities of No. 5 and No. 13.

Violet....Equal quantities of No. 7 and No. 11.

Pitch-black....Three parts of No. 12 with one of No. 4.

Ink-black....Three parts of No. 12 with one of No. 4. It is again rendered limpid by No. 6; and No. 13 turns it blue.

For these amusing experiments we are indebted to Mr. Tielebein.

WHITENESS.

The most curious composition of light is that of whiteness. There is no one sort of rays which can alone exhibit this colour; it is always compound, and to its composition all the aforesaid primary colours are necessary. It is the most surprising composition, an assemblage of all the colours of the prism, in union in a due proportion. *Whiteness therefore, or the solar light, is always compound:* it is produced by a copious reflection of the rays of all sorts of colours.

A spinning top painted on the surface with the colours of the spectrum of the prism may serve to prove this. On spinning the top, it revolves rapidly on its axis; while it is so revolving, none of the colours can possibly be distinguished singly, but the whole appears *white;* this whiteness will be greater in proportion as the primitive colours are brighter.

BLACKNESS,

On the contrary, is produced by a total absorption of the incidental light, which being stopped or absorbed in the body is not reflected outwards, but refracted within; hence it is lost, and produces darkness.

Such are the principal physical properties of light. Optical writers may be consulted for a great number of curious and useful deductions made from these principles and applied to the doctrine of vision, the nature of colours, the construction of mirrors, and other instruments, not immediately within the province of chemistry.

SECT. V.

CHEMICAL PROPERTIES OF LIGHT.

THE chemical effects of light have much engaged the attention of philosophers. Its influence upon animal, vegetable, and other substances, shall form the subject of the following heads.

1. EFFECTS OF LIGHT ON VEGETABLES.

Every body knows that most of the discous flowers follow the sun in his course; that they attend him to his evening retreat, and meet his rising lustre in the morning with the same unerring law. It is also well known that the change of position in the leaves of plants at different periods of the day is entirely owing to the agency of light, and that plants which grow in windows in the inside of houses are, as it were, solicitous to turn their leaves towards the light. Natural philosophers have long been aware of the influence of light on vegetation. It was first observed that plants growing in the shade, or darkness, are pale and without colour. The term *etiolation* has been given to this phenomenon, and the plants in which it takes place are said to be *etiolated* or *blanched*. Gardeners avail themselves of the knowledge of this fact to furnish our tables with white and tender vegetables. When the plants have attained a certain height, they compress the leaves, by tying them together, and by these means (or by laying earth over them) deprive them of the contact of light: and thus it is that our white celery, lettuce, cabbages, endive, &c. are obtained. For the same reason wood is white under the green bark; roots are less coloured than plants, some of them alter their taste, &c. they even acquire a deleterious quality when suffered to grow exposed to light. Potatoes are of this kind. Herbs that grow beneath stones, or in places utterly dark, are white, soft, aqueous, and of a mild and insipid taste. The more plants are exposed to the light, the *more colour* they acquire. Though plants are capable of being nourished exceedingly well in perfect ob-

scurity, and in that state they even grow much more rapidly than in the sun (provided the air that surrounds them is fit for vegetation) they are colourless, and unfit for use.

Professor Davy* assures us that red rose-trees carefully excluded from light produced roses almost white. He likewise ascertained that this flower owes its colour to light entering into its composition; that pink, orange, and yellow flowers imbibe a smaller proportion of light than red ones, and that white flowers contain no light.

But vegetables are not only indebted to the light for their colour: taste and odour are likewise derived from the same source.

Light contributes greatly to the maturity of fruits and seeds. This seems to be the cause why under the burning sun of Africa vegetables are in general more odoriferous, of a stronger taste, and more abounding with resin. From the same cause it happens that hot climates seem to be the native countries of perfumes, odoriferous fruits, and aromatic resins.

The action of light is so powerful on the organism of vegetables, as to cause them to pour forth torrents of pure air from the surface of their leaves into the atmosphere, while exposed to the sun; whereas, on the contrary, when in the shade they emit an air of a noxious quality.

Experiment I.

Take a few handfuls of fresh gathered leaves of mint, cabbage, or any other plant; place them in a bell-glass filled with fresh water, and invert it into a basin with the same fluid. If the whole be then exposed to the direct rays of the sun, small air bubbles will appear on the surface of the leaves, which gradually grow larger, and at last detach themselves and become collected at the surface of the water. This is oxygen gas.

All plants do not emit this air with the same facility: there are some which yield it the moment the sun acts upon them, as the leaves of the jacobœa or ragwort, of lavender, peppermint, and some other aromatic plants. The leaves afford more air when attached to the plant than

* Beddoe's Physical and Medical Contributions, p. 790.

when gathered; the quantity is also greater the fresher and sounder they are, and if full grown and collected during dry weather. Green plants afford more air than those which are of a yellowish or white colour. Green fruits afford likewise oxygen gas; but it is not so plentifully furnished by those which are ripe. The nasturtium indicum, in the space of a few hours, gives out more air than is equal to the bulk of all its leaves.

On the contrary, if a like bell-glass, prepared in the same manner, be kept in the dark, another kind of air will be disengaged, of an opposite quality. The method of collecting and examining these gases will be shown hereafter, and the philosophy of their production will then be more fully pointed out.

There is not a substance which, in well-closed glass vessels, and exposed to the sun's light, does not experience some alteration.

Camphor kept in glass bottles exposed to light crystallizes or vegetates into the most beautiful symmetrical figures, on that side of the glass which is exposed to the light.

Yellow wax exposed to the light loses its colour, and becomes bleached. Gum guaiacum, reduced to powder, becomes green on exposure to light. Vegetable colours, such as those of saffron, logwood, &c. become pale or white, &c.

2. EFFECTS OF LIGHT ON ANIMALS.

The human being is equally dependent on the influence of light.

Animals in general droop when deprived of light: they become unhealthy, and even sometimes die. When a man has been long confined in a dark dungeon (though well aired) his whole complexion becomes sallow, pustules filled with aqueous humours break out on his skin, and the person who has thus been deprived of light becomes languid, and frequently dropsical.

Worms, grubs, and caterpillars, which live in the earth, or in wood, are of a whitish colour; moths, and other insects of the night, are likewise distinguishable from those which fly by day, by the want of brilliancy in their colour.

The difference between those insects in northern and southern parts is still more obvious.

The parts of fish which are exposed to light, as the back, fins, &c. are uniformly coloured; but the belly, which is deprived of light, is white in all of them.

Birds which inhabit the tropical countries have much brighter plumage than those of the north. Those parts of the birds which are not exposed to the light are uniformly pale. The feathers on the belly of a bird are generally pale or white; the back which is exposed to the light, is almost always coloured; the breast which is particularly exposed to light in most birds, is brighter than the belly.

Butterflies, and various other animals of equatorial countries, are brighter coloured than those of the polar regions. Some of the northern animals are even darker in summer, and paler in winter.

3. EFFECTS OF LIGHT ON METALLIC OXYDS.

Experiment I.

Effects of light on muriate of silver.

Dissolve pure silver in nitric acid, and add to it muriatic acid, a decomposition will take place; for the muriatic acid, having a stronger affinity to silver than the nitric acid, will unite to it, and fall to the bottom as an insoluble compound called muriate of silver.

Separate this muriate by pouring the whole on a filter as quick as possible, and expose it still wet to the light, on a plate of white glass, on the lower side of which black paper has been pasted: at the end of some hours it will be seen that the light has exercised no action but at the surface, where the muriate will be found blackened, or re-approaching to the metallic state; while at the place where the light did not fall there will be no alteration.

Mr. T. Wedgwood has availed himself of the property which light exercises upon the metallic oxyds for copying paintings upon glass, and making profiles of figures by the mere agency of light upon nitrate of silver, in the following manner:*

* Journals of the Royal Institution, No. 9. p. 171.

Experiment II.

Let white paper or leather be covered with a solution of nitrate of silver, place it behind a painting on glass, and expose it to the solar light; the rays emitted through the differently painted surfaces will produce distinct tints of brown or black, sensibly differing in intensity, according to the shades of the picture; and where the light is unaltered the colour of the nitrate becomes deepest.

When the shadow of any figure is thrown upon the prepared surface, the part concealed by it remains white, and the other parts speedily become dark.

For copying paintings on glass, the solution should be applied on leather; and in this case it is more readily acted upon than when paper is used.

After the colour has been once fixed upon the leather or paper, it cannot be removed by the application of water, or water and soap, and it is in a high degree permanent.

The copy of a painting, or the profile, immediately after being taken, must be kept in an obscure place. It may indeed be examined in the shade, but, in this case, the exposure should be only for a few minutes; by the light of candles or lamps, as commonly employed, it is not sensibly affected.

No attempts that have been made to prevent the uncoloured parts of the copy or profile from being acted upon by light have as yet been successful. They have been covered with a thin coating of fine varnish, but this has not destroyed their susceptibility of becoming coloured; and even after repeated washings, sufficient of the active part of the saline matter will still adhere to the white parts of the leather or paper to cause them to become dark when exposed to the rays of the sun.

'Besides the applications of this method of copying that have been just mentioned, there are many others. And it will be useful for making delineations of all such objects as are possessed of a texture partly opaque and partly transparent. The woody fibres of leaves, and the wings of insects, may be pretty accurately represented by means of it; and in this case, it is only necessary to cause the direct solar light to pass through them, and to receive the shadows upon prepared leather.

When the solar rays are passed through a print and thrown upon prepared paper, the unshaded parts are slowly copied; but the lights transmitted by the shaded parts are seldom so definite as to form a distinct resemblance of them by producing different intensities of colour.

Professor Davy has found, that the images of small objects produced by means of the solar microscope may be copied without difficulty on prepared paper. This will probably be a useful application of the method; that it may be employed successfully, however, it is necessary that the paper be placed at a small distance from the lens.

With regard to the preparation of the solution, this gentleman found the best proportions those of one part of nitrate to about ten of water. In this case, the quantity of the salt applied to the leather or paper will be sufficient to enable it to become tinged, without affecting its composition, or injuring its texture.

Count Rumford has made some valuable experiments concerning the chemical properties that have been attributed to light.* This philosopher observed, that white ribands wetted in a diluted aqueous solution of muriate of gold, and exposed wet to the action of the sun's direct rays, soon become tinged of a beautiful crimson colour. Magnesia wetted with a solution of muriate of gold, and exposed wet to the action of the sun's rays, soon changes to a purple, and afterwards to a deep crimson colour. But if the riband or magnesia, after being so wetted, be dried in a dark place, and then exposed in a dry state to the sun's rays, their colour will not be sensibly changed by the action of the light.

The following method of silvering ivory, which we shall transcribe from the Count's paper,† is extremely beautiful, and may become a valuable acquisition to the arts.

Experiment III.

Take a slip of ivory, immerse it in a diluted solution of pure nitrate of silver, and suffer it to be immersed till the ivory has acquired a bright yellow colour; then take it out of the solution, and immerse it in a tumbler of pure

* Rumford's Philosoph. Papers, vol. 1, 1802, p. 22.
† l. c. p. 363.

water, and immediately expose it, in the water, to the direct rays of a bright sun. After the ivory has been thus exposed for about two or three hours to the action of the sun's light, it will appear black; but on rubbing it a little, the black surface will become changed into a metallic one, resembling a slip of fine silver.

Although this coating of revived metal is extremely thin, yet if the ivory be well impregnated with the nitrate of silver the solution will penetrate to a considerable depth, and as fast as the silver wears off from the surface of the ivory, the oxyd below it becoming uncovered, and exposed to the light, a new coating of revived metal will be formed to replace it, and the surface of the ivory will not lose its metallic appearance.

The Count further observes, that this method of silvering ivory, which is not only expeditious, but very economical, might, no doubt, be employed with advantage in many cases, for ornamental purposes. The process is certainly curious and beautiful, when considered merely as a philosophical experiment.

All metallic oxyds, but especially those of mercury, bismuth, lead, silver, and gold, become of a deeper colour, by exposure to the sun; some of them become perfectly revived, others only partially, as may be seen by observing various painters' colours, preserved in powder, and exposed to the light, in the windows of colour-shops. The yellow oxyd of mercury, the acetate and muriate, are very soon affected by light.

The black oxyd of mercury, obtained by pouring ammonia copiously into a neutral solution of sulphate of mercury (or rather on dry sulphate) exposed to the rays of light, becomes readily converted into fluid quicksilver.

The yellow oxyd of tungsten, if exposed to light, loses weight and becomes blue.

Green prussiate of iron exposed to the solar light becomes also blue.

The rose-coloured solution of sulphate of manganese becomes colourless when kept exposed to the light, and regains its colour when removed into the dark.

4. EFFECTS OF LIGHT ON ACIDS.

Experiment I.

Decomposition of nitric acid by light.

If a white glass bottle be half filled with concentrated nitric acid, and exposed to the rays of the sun, at the end of some days the white acid will be converted into an orange-coloured and fuming one, and the bottle will become filled with red vapours. If the bottle be now carried into a dark place and suffered to remain there for some time, the red vapours will gradually diminish, and the acid return to its primitive or colourless state.

Nitric acid, as we shall see hereafter, consists of the basis of two aeriform fluids, called nitrogen and oxygen. The acid in this instance loses part of its oxygen, which unites with the light, and forms oxygen gas; hence the acid becomes more volatile, and fuming.

This experiment succeeds best with highly concentrated acid, exposed to the light in bottles only half filled.

If oxygenated muriatic acid be exposed to the light, oxygen gas may easily be obtained, in the following manner, in considerable quantity.

Experiment II.

Decomposition of oxygenated muriatic acid by light.

Put concentrated oxygenated muriatic acid into a bottle, and fit to it a bent glass tube, one end of which pierces the cork of the bottle, and the other end reaches under a bell or receiver, filled with and inverted in a basin of water, care being taken that the tube does not touch the acid; the light falling directly on the acid, decomposes it, and a part of the oxygen of the acid becomes disengaged in the gaseous form, and passes into the receiver.

Thus, there remains no doubt that light acts chemically on various substances. We have seen that incombustible bodies, such as oxyds of metals, become combustible when exposed to the light; that acids are decomposed by its contact; that various other substances change their nature; that vegetables acquire colour, odour, taste, and in-

flammability: whereas, on the contrary, deprived of light they remain pale and insipid, and are what is called *etiolated*, or blanched.

Light therefore enters into the composition of bodies; and its effects are so considerable, that the skilful operator ought to be constantly aware of the influence it may have upon the products submitted to his investigation.

SECT. VI.

COMBINATION OF LIGHT WITH DIFFERENT BODIES.

Philosophers have ascertained that various bodies, if exposed to light either at a high or low temperature, combine with it and emit it again, without alteration, under certain circumstances.

Substances of this kind have been called **SOLAR PHOSPHORI**, or substances which shine in the dark without emitting heat, after having been exposed to the light.

The world is stocked with an immense variety of bodies of this kind. All terrestrial objects not only possess a power of absorbing light, but they likewise emit it again. The eyes of cats, owls, and several other animals, are constructed so as to collect light, to enable them to find their food in the dark. Water condensed into the form of ice or snow, emits light remarkably. This accounts for the light afforded by snow, even when the heavens are involved in extreme darkness. The snow on the ground absorbs light, by being exposed to it all the day, and emits a considerable quantity again in the dark.

The principal bodies of this kind are the following:

Bolognian phosphorus....The process for preparing this phosphorus is as follows: pieces of sulphate of barytes are first made red-hot, for a few minutes, in a covered crucible, placed in the middle of a fire, and then left to cool. When cold they are pulverized in a stone mortar, and sifted. This powder is formed into a paste with a

little mucilage of gum arabic, and divided into cakes, cylinders, or pieces of the thickness of a quarter of an inch. Those pieces are dried in a moderate heat, and then exposed, by degrees, to a more violent heat, among charcoal, in a strong drawing wind-furnace. As soon as the coals are half consumed, the furnace must be filled a second time, and the phosphorus be left undisturbed. When the coals are quite consumed, the ashes must be carefully blown off with a pair of bellows, and the phosphorus is found at the bottom of the grate.

These phosphoric stones exposed for a few minutes to the light, shine when taken into the dark like burning coals. Even immersed in water, they emit the same glowing light. Not only this phosphorus, but likewise all other phosphori of this class, lose their luminous property gradually, which they however regain on being heated a second time.

RATIONALE....During the process of preparing the Bolognian phosphorus, a partial decomposition of the sulphuric acid of the sulphate of barytes takes place. The ignited charcoal, at a high temperature, has a greater affinity to the oxygen of the sulphuric acid than the sulphur has; it therefore attracts it, and forms carbonic acid gas; part of the sulphur of the sulphuric acid becomes thus separated; it unites to the pure barytes, and forms sulphuret of barytes, which seems in this union more disposed to decompose oxygen gas than when single. The phenomenon is therefore to be considered analogous to a slow combustion of the sulphur; the extrication of caloric, during each instant of observation, being too inconsiderable to be appreciable either by the senses or by the thermometer.

CANTON'S PHOSPHORUS....To prepare this phosphorus, take some oyster shells; calcine them, by keeping them in a good coal-fire, for about an hour. Then let the purest part of the lime so obtained be broken into pieces (not powdered.) To three parts of it, add one of flowers of sulphur, and place the whole in layers, in a crucible, tightly. Let it then be placed in the middle of a fire, where it must be kept red hot for an hour at least; it may then be removed to cool. When it is cold, select the brightest part, which, if good, will shine in the dark. This is to be kept in a wide-mouthed glass phial, well closed.

This is Canton's phosphorus. The quantity of light which a little of it gives, when brought into a dark room, after it has been exposed for a few minutes to the sun, or even day-light, is sufficient to show the hour by a watch, if the eyes have been previously kept shut a minute or two.

RATIONALE....Analogous to the former.

BALDWIN'S PHOSPHORUS....Is a combination of nitric acid with lime, obtained by dissolving carbonate of lime in nitric acid, and evaporating the solution in an earthen vessel to dryness. This solid salt is then to be rammed into a crucible, which is placed in the middle of a good fire, where it is to be kept till the whole mass becomes liquid. As soon as the mass has fused about eight minutes, the crucible is to be removed, and its contents poured out into an iron pot, previously heated. This mass, when still hot, is to be preserved from the contact of the air in a well-stopped phial.

Baldwin's phosphorus, when well prepared, shines with a beautiful white light, after having been exposed to the sun for a few hours.

Modern observations have made us acquainted with several other bodies which possess the property of shining, after having been exposed to an elevated temperature. We know that not only all neutral salts with a base of barytes belong to this class, but also many other substances, namely, diamonds, and several precious gems, magnesia, carbonate of magnesia, sulphate and carbonate of lime, alumine earth, sulphate of potash, sulphate of strontian, some metallic oxyds, cotton wool, appatite, zeolite, &c. display the same phenomena.

The combination of fluoric acid with lime, commonly called fluor spar or fluate of lime, is remarkable on account of its property of shining in the dark, at an elevated temperature only. When the phosphoric fluor spar is reduced to a fine powder, and placed in contact with any body, heated to about 212° Fahr. though not ignited, and afterwards taken into a dark place, it shines with a phosphoric light. By this means may be performed writings, drawings, &c. upon an iron or copper plate, with a thin mucilage of gum arabic, or with white of egg, and strewing over it some fine powdered fluate of lime. When this is dry, all the superfluous powder must be carefully blown off, and the plate removed over a gentle coal fire. As soon

as it is heated the delineated objects become luminous, and opaque again when the plate becomes cold.

Not only lapis lazuli, several kinds of stones, &c. become luminous in a high temperature; but also Dr. Marum observed, that a phosphoric light is discernible in expressed oils and animal fats, when heated to 450° Fahr.

PHOSPHORIC SUBSTANCES WHICH BECOME LUMINOUS BY ATTRITION OR PERCUSSION.

The most celebrated and most anciently known body of this kind is called

HOMBERG'S PHOSPHORUS....Homberg's process for obtaining this phosphorus is as follows: one part of powdered muriate of ammonia is mixed with two of powdered lime, introduced into a red-hot crucible, and kept hot till the mixture becomes liquid. As soon as the mass has been fused for a few minutes, it is poured out into a heated iron pot, broken into pieces, and preserved in a well-stopped phial.

This substance has the property of emitting a phosphoric light, when struck or excited with a hard sharp body in the dark. When a red hot poker is dipped into the fused substance, and rubbed after it is cool with another piece of metal, it becomes luminous, and gives out phosphoric sparks and light.

This phosphorus is obtained more conveniently, as well as at less expence, when that portion of muriate of lime which remains in the retort, after the decomposition of muriate of ammonia by lime, is melted, and then exposed for some minutes to such a degree of heat as is sufficient to melt the surface of a green glass matrass; it acquires the property of giving fire with steel, and emits phosphoric sparks and flashes of light in a high degree.

Those kind of phosphori or substances which give a perceptible sparkling light by attrition or percussion, without having been exposed either to the solar light or fire, are likewise numerous. Flints, and several other siliceous stones, struck against one another, appear luminous in the dark, some through the whole mass, others only on the side struck upon. Tremolit, phosphate of lime, black-jack, and other stones of this genus, become luminous or yield

phosphoric light in the dark, when struck with a sharp instrument. Gum elemi, various resins, and sugar, emit a perceptible light by attrition or percussion, without having been exposed to light or heat.

Mr. T. Wedgwood* has published an excellent paper on the light produced by attrition.

Mr. Coates† of Clifton observed, that if two pieces of bonnet-cane were rubbed together in the dark, light was liberated. Professor Davy, who pursued this experiment, found that all canes of this kind when briskly rubbed together produce sparks of white light, which are more vivid on collision.

But the most perfect phosphorus of this class is subborate of soda. Two pieces of this salt struck one against another, or a swift blow with any sharp instrument upon it, produces such a flash of white light, as none of the before-mentioned substances are capable of giving.

Other substances again emit light on immersion into acids.

Mr. Westrumb‡ observed, that when fresh prepared magnesia is thrown into concentrated sulphuric acid, light is liberated, which produces an appearance similar to that known by the name of red heat.

Experiment I.

To perform this experiment, about two scruples or one drachm of magnesia, recently freed from carbonic acid by heat, must be put into a tea-cup, and half an ounce of highly concentrated sulphuric acid poured over it at once, so as to cover the magnesia. A prodigious quantity of vapour is instantly extricated; sparks are thrown about, and the mixture becomes ignited. Mr. Westrumb observed, that coloured (or partly deoxygenized) sulphuric acid answered the purpose better than when the acid was colourless.

During the combination of lime with muriatic acid, and of dry potash or soda with sulphuric acid, a white light is uniformly perceived.

* Philosoph. Trans. 1792.
† Nicholson's Journal, May, 1799, p. 56.
‡ Crell's Chemic. Annals, 1784, p. 432.

Various animal and vegetable substances likewise emit light, under peculiar conditions only. Fish, and several other marine animals, both in a living state and when dead, possess this property; as instances of the first may be mentioned the shell-fish called *pholas*, the *medusa* phosphorea, and various other *molluscæ*.

In the class of insects are many which emit light very copiously, particularly several species of *fulgora*, or lantern fly; and of *lampyris*, or glow-worm: also the *scolopendra electrica*, and a species of crab, called *cancer fulgens*.

Rotten wood is well known to emit light spontaneously. Peat earth has the same property.

The flesh of quadrupeds has also been observed to emit light.

The softest parts become often totally phosphoric; it appears in this state as if sprinkled over with gems. Upon touching the brilliant luminous particles they come off, and appear almost liquid.

The medullary substance of the brain of human beings, or rather the nervous system in general, is said to possess this property in a high degree: it is this particularly which gives rise to those phosphorescent lights frequently observed in anatomical theatres. Citizen Cabarris, who read a memoir on this subject before the national institute, remarks, that a variety of observations have made him conclude, that the quantity of phosphorescent matter after death bears some proportion to the activity of the nervous system during life.

Dr. Hulme has made some interesting experiments on the light which is spontaneously emitted from various bodies. He believes (as is highly probable) that the light is a constituent part of many animals, particularly of the marine fishes; that it may be separated, collected, and rendered permanent for some time by peculiar processes, for which we refer our reader to the interesting, curious, and well-conducted experiments enumerated in his paper.*

NATURE OF THE PHOTOMETER.

In order to measure the relative intensity of light emitted by luminous bodies, various kinds of contrivances, call-

* Philospho. Trans. 1800, p. 161.

ed PHOTOMETERS, have been contrived. The most perfect instruments of that kind are the photometer of Count Rumford and that of Mr. Leslie. Count Rumford's method of measuring the comparative intensity of two lights, is to place the two lights at such distances from a given plane, that the shadows cast by them appear equally dark; and since the intensity of light must obviously decrease as the square of the distance increases, it becomes easy to calculate from the distance determined, the original density of the lights compared. The Count found by means of his photometer, that the saving in the quantity of oil consumed by an Argand's lamp, compared with one of the common construction with a riband wick, amounted to about 15 *per cent.* in the production of an equal quantity of light. He also ascertained, that an Argand's lamp of the common size well trimmed, and burning with its greatest brilliancy, emitted about as much light as ten common wax candles, each three-quarters of an inch in diameter; and that the light of a good wax candle varies from 100 to about 60: if, namely, such a candle when newly snuffed, and burning with its greatest brilliancy, emits a quantity of light = 100, its light will be reduced to 20, and even as low as 16, when it is suffered to burn very dim for want of being snuffed. The loss of light emitted by a tallow candle under similar circumstances was found to be much greater. A particular account of the principles on which count Rumford's photometer is founded, together with some masterly drawings of the instrument, may be found in Count Rumford's work,* from which these *data* have been copied.

The ratio of the intensities of luminous bodies, for instance, two candles of unequal size, may also be measured with tolerable accuracy, by placing them at different distances from a given object, until that object casts two shadows of equal density or darkness; or by observing when two equal objects appeared to be equally illuminated, each by one of the luminous objects: for then the proportion of the intensities of their lights was reckoned to be as that of the square of distances: for instance, if two equal objects appear to be equally illuminated, when one of them is three feet from a tallow candle, and when the

* Rumford's Philosophical Papers, 1802, p. 270.

other is nine feet from a wax candle, then it is concluded that the intensity of the light of the tallow is to that of the wax candle as 9 to 81.

Thus far we have examined the two imponderable substances diffused through space, namely caloric and light. They have been considered by different philosophers as substances whose particles mutually repel each other, for they are never found cohering together.

They agree in many of their properties: they radiate from hot or luminous bodies with inconceivable velocity; they are transmitted, reflected, and refracted, by different substances; while they have the property of combining with others.

CALORIC, we have seen, is the cause of the sensation of heat; it produces expansion, is the cause of fluidity, &c.

LIGHT, on the other hand, produces the sensation of vision, and is the cause of colours. Both substances do not effect the ponderability of bodies. All attempts to weigh them have hitherto been in vain; they have therefore been called IMPONDERABLE SUBSTANCES: if they are absolutely *imponderous*, is left to the determination of the more successful labours of future inquirers.

SUBSTANCES NOT YET PRODUCIBLE BY ART, BUT ANALOGICALLY CONSIDERED AS SIMPLE.

PART X.

SECT. I.

OXYGEN.

AS the two agents which have formed the subject of our last inquiry may be considered as the great instruments of analysis and synthesis in the phenomena of nature; so likewise will those substances which will form the subjects of the present part, though long unknown, or ill understood to men, prove no less interesting, and entitled to our attention. They afford to our art instruments and means not less important, and necessary to be known.

Oxygen, though long concealed from chemists, and as it were eluding the ancient methods of analysis in their possession; though it be an independent substance very distinct from every other, it is not easy to give a clear notion or precise definition of this body, because this substance, existing sometimes in a solid and sometimes in an aeriform state, is never distinctly perceptible to the human senses, but in combination. Nevertheless, it can be weighed and measured, combined and disengaged.

We know it only in its combination, by its effects. Nature never presents it solitary; chemists do not know how to insulate it. We are therefore obliged to consider it at first as an abstract being, or metaphysical entity, when we wish to avoid speaking of its combinations.

Oxygen is absorbable by combustible bodies, and converts most of them into acids. This is, in fact, one of the most characteristic properties of this body, first discovered by Dr. Priestly in the year 1774. It is an indispensable condition of combustion, uniting itself always to bodies which burn, augmenting their weight and changing their properties. It may be disengaged in the state of oxygen gas from burnt bodies, by a joint accumulation of caloric and light. It is highly necessary for the respiration of animals, and for the support of plants. It exists universally dispersed through nature, and is a constituent part of atmospheric air, of water, of acids, and of all bodies of the animal and vegetable kingdoms.

One of the most remarkable combinations into which it is capable of entering, is that which it forms with light and caloric. The nature of that mysterious union has not been ascertained; but it is certain that in that state it constitutes the gaseous fluid called OXYGEN GAS, which it will be more proper to consider hereafter.

The combination of oxygen with different bases, is called *oxygenation*, *oxygenisement*, *oxydation*, or *oxydisement*.

SECT. II.

HYDROGEN.

Hydrogen is another substance not perceptible to our sensations in a separate state; but its existence is not at all the less certain. Though we cannot exhibit it experimentally uncombined, we can pursue it while it passes out of one combination into another: we cannot indeed arrest it on its passage; but we never fail to discover it, at least if we use the proper chemical means, when it presents itself to our notice in a new compound.

Hydrogen, as its name expresses, is one of the constituent elements of water. Its existence was unknown till lately. It is plentifully distributed in nature, and acts a very considerable part in the processes of the animal and vegetable economy. It is one of the ingredients in the mixtures of bitumen, of oils, fats, ardent spirit, ether, and in fact of all the proximate component parts of all animal

and vegetable bodies. It forms a constituent part of all animal and vegetable acids. It is one of the bases of ammonia, and of various other compound gases.

It possesses so great an affinity with caloric, that it can only exist in the state of gas: it is consequently impossible to procure it in the concrete or liquid state, independent of combination.

Solid hydrogen, therefore, united to caloric and light, forms HYDROGEN GAS, which will be noticed in its proper place.

SECT. III.

NITROGEN.

Nitrogen or azote is another simple body in the same condition with regard to us as hydrogen and oxygen. It is very abundant in nature, though not producible alone or in an insulated state. It is not distinctly perceptible to the human senses, however aided by instruments. We know it only in its combination. But the reality of its existence is unquestionable; since we can mark its passage out of one combination into another; since we know the laws of chemical attraction to which it is subject; since we discern the precise character of those simple substances with which it is combinable, and can distinguish the nature of the new compounds which the combination produces. The separate existence and peculiar nature of this substance were first discovered by Dr. Rutherford. It is the radical principle of our atmospheric air, and other gaseous substances, and forms a constituent part of animal and vegetable substances. It is a component part of the nitric acid, and of ammonia. It probably enters into the formation of alkalies, and it is considered by some as a real alkaligen or alkalizing principle, in opposition to oxygen, which, as we have noticed before, is the principle of acidity. One of the most remarkable combinations into which nitrogen is known to enter, is that which takes place between it and light and caloric. The compound thus produced is called NITROGEN GAS, which shall be treated of in a farther part of this work.

We have noticed these three substances here separately, because they act so very important a part in all the phenomena of chemistry, that it is requisite to have some previous notion of them before we proceed any farther. They shall be more circumstantially described hereafter, together with the rest of the bodies enumerated before in the table of simple substances.

COMBUSTIBLE BODIES, DESTITUTE OF METALLIC PROPERTIES.

SULPHUR.

PART XI.

SECT. I.

NATURAL HISTORY OF SULPHUR.

SULPHUR, which is also known by the name of brimstone, is the only simple combustible substance which nature offers pure and in abundance. It was the first known of all. It was on this substance that the ingenious Stahl most particularly established his theory of phlogiston, which has governed the schools during a century. In general, sulphur, even considered as a principal subject in chemistry, has been at all times one of those which have participated the most in the different changes which the science has experienced, and concerning which philosophers have been more particularly employed. Sulphur is consequently a body whose combinations are the most numerous, and, at present, the best understood.

It is found abundantly in the earth, and exists externally in depositions, in sublimed incrustations, and on the surface of certain waters, principally near burning volcanoes. It is found combined with many metals. It exists in vegetable substances, and has lately been discovered by Mr. Carlisle in the albumen of eggs.*

Sulphur in the mineral kingdom is either in a loose powder, or compact and crystallized; and then either detached or in veins. It is found in the greatest plenty in

* Nicholson's Journal, August, 1801, p. 178.

the neighbourhood of volcanoes or pseudo-volcanoes, whether modern or extinct, as at *Solfatara*, &c. and is deposited as a crust on stones contiguous to them, either crystallized or amorphous. It is frequently met with in mineral waters, and in caverns adjacent to volcanoes; sometimes also in coal-mines. It is found in combination with most of the metals. When united to iron it forms the mineral called *martial pyrites*, or *sulphur pyrites*. All the ores known by the name of *pyrites*, of which there are a vast variety, are combinations of sulphur with different metals; and hence the names of copper, tin, arsenical, &c. pyrites. It exists likewise in combination with alumine and lime; it then constitutes different kinds of schistus, or alum ores.

It occurs commonly in masses in gypsum and marls. It is sometimes found in veins that traverse primitive rocks. It occurs also in nests in lime-stone. Very lately the celebrated and enterprising Prussian traveller Von Humboldt has discovered a bed composed of sulphur and quartz, in a mountain of micaceous slate.*

Sulphur is found in Europe, at Baaden in Austria, at Lauenstein in Hanover, at Artern in Thuringia, Schwartzwalde in Swabia, at Jura in Switzerland, Lothringen in France, in the mountains of Grenada, Andalusia, and Conil, near Cadiz, in Spain.

What is called by mineralogists volcanic sulphur occurs only in volcanic countries; where it is found in greater or smaller quantity amongst lava, Solfatara, in the vicinity of Vesuvius, &c.

PHYSICAL PROPERTIES OF SULPHUR.

Sulphur is a combustible, dry, and exceedingly brittle body, of a pale lemon-yellow colour. Its specific gravity is 1.990. It is destitute of odour, except when rubbed or heated. It is of a peculiar faint taste. It frequently crystallizes in entire or truncated octahedra, or in needles. If a piece of sulphur of a considerable size be very gently heated; as for example, by holding it in the hand and squeezing it firmly; it breaks to pieces with a crackling noise. It is a non-conductor of electricity, and hence it becomes electric by friction. When heated, it first softens

* Annales du Museum National.

before it melts, and its fusion commences at 184° Fahr.; at 289° it becomes volatilized, and takes fire at 302°. In the beginning of fusion it is very fluid, but by continuing the heat it grows tough, and its colour changes to a reddish brown. If in this condition it be poured into water, it remains as soft as wax, and yields to any impression. In time, however, it hardens again, and recovers its former consistence.

It unites with most of the earths and with all alkalies, with muriatic acid, and becomes soluble, when thus combined, in water. It unites to most of the metals, and renders them brittle and fusible. It is soluble in oils; water takes up a minute quantity, as does ardent spirit and ether by means of heat. It dissolves in hydrogen gas, and unites to phosphorus by fusion.

Sulphur, like all combustible bodies, burns in proportion to the quantity of oxygen which combines with it.

If melted sulphur be exposed in the open air to an increase of heat, it takes fire, and burns with a blue flame and suffocating vapour. The result of this combustion is sulphureous acid. According to the slow or rapid combustion, it absorbs different quantities of oxygen, and the produced acid differs in its properties. Sulphur heated in a close vessel sublimes without alteration. It is not changed by exposure to air. It is attacked by the nitric acid when poured on it in its fused state.

METHOD OF OBTAINING SULPHUR.

A prodigious quantity of sulphur is obtained from Solfatara, in Italy. This volcanic country every where exhibits marks of the agency of subterraneous fires: almost all the ground is bare and white; and is every where sensibly warmer than the atmosphere, in the greatest heat of summer; so that the feet of persons walking there are burnt through their shoes. It is impossible not to observe the sulphur; for a sulphureous vapour which rises through different apertures is every where perceptible, and gives reason to believe that there is a subterraneous fire underneath from which that vapour proceeds.

From pyrites sulphur is extracted in the large way by the following process:

Pyrites is broken into small pieces, and put into large earthen tubes, which are exposed to the heat of a furnace. A square vessel of cast-iron, containing water, is connected as a receiver with the tube in the furnace. The action of the fire proceeds, and the sulphur being thus melted is gradually accumulated on the water in the receiver. It is then removed from this receiver, and melted in large iron ladles; in consequence of which, the earthy parts with which it was contaminated are made to subside to the bottom of the ladle, leaving the purified sulphur above. It is then again melted, and suffered to cool gradually, in order to free it from the rest of the impurities. It is then tolerably pure, and constitutes the sulphur we meet with in large masses or lumps in the market.

In order to form it into rolls, it is again melted and poured into cylindrical wooden moulds: in these it takes the form in which we usually see it in commerce, as roll sulphur.

Flowers of sulphur, as they are called, are formed by subliming purified sulphur with a gentle heat in close rooms, where the sublimed sulphur is collected; though the article met with in general, under that name, is nothing but sulphur finely powdered.

METHOD OF PURIFYING SULPHUR.

Take one part of flowers of sulphur, boil it in twenty parts of distilled water in a glass vessel for about a quarter of an hour; let the sulphur subside, decant the water: and then wash the sulphur repeatedly in distilled water; having done this, pour over it three parts of pure nitro-muriatic acid, diluted with one part of distilled water; boil it again in a glass vessel for about a quarter of an hour, decant the acid, and wash the sulphur in distilled water till the fluid passes tasteless, or till it does not change the blue colour of tincture of cabbage, or litmus. The sulphur thus carefully treated is PURE SULPHUR, fit for philosophical experiments.

We shall now endeavour to prove some of the before stated properties of sulphur.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF SULPHUR.

EXPERIMENT I.

Slow combustion of sulphur.

PUT some threads previously dipped in sulphur into a cup or other vessel floating on water. Set fire to the threads, and cover the whole with an inverted glass receiver. The threads will continue to burn for some time, and the whole receiver will become filled with a dense white vapour. The water will ascend into the receiver. The whole is then to be left till the vessel is become again transparent. If the water be now examined, it will have a suffocating odour and taste. It will turn the blue colour of litmus paper red, and exhibit all the other signs that an acid has been formed.

RATIONALE...The sulphur, being a simple body, has at an elevated temperature a great affinity to oxygen; it therefore attracts it from the atmospheric air, and thus becomes converted, by slow combustion, into sulphureous acid gas, which is absorbed by water. The volume of air within the receiver being diminished, is the cause of the ascent of the fluid.

This experiment may perhaps be more conveniently performed by covering burning sulphur contained in a crucible with a large receiver, and then placing the apparatus in a broad dish, and surrounding it with water.

EXPERIMENT II.

Rapid combustion of sulphur.

Take a large receiver, or any other round-bellied bottle with a wide orifice, containing a little water; fit a bung

to close it, and fasten to this bung an iron or copper spoon, containing a mixture of one part of nitrate of potash and six of sulphur, blended together. Set fire to the mixture, and introduce it expeditiously into the vessel, taking care to close the mouth accurately. In this case, the combustion will go on very rapidly, and the water at the bottom of the vessel will become sour, but without possessing much suffocating odour.

RATIONALE....In this experiment the combustion is not slow, but on the contrary very rapid; for the nitric acid of the nitrate of potash is decomposed, and furnishes oxygen gas, into which the sulphur is plunged the instant of its inflammation. It therefore absorbs a much greater quantity of oxygen, and furnishes *sulphuric acid*, different in properties from the former, which is not completely oxygenated, and therefore is pungent and volatile.

EXPERIMENT III.

Sulphur is soluble in ardent spirit only in a state of extreme comminution.

If a piece of sulphur be left in contact with ardent spirit for any length of time, the spirit will not act upon it; but if we present the sulphur in its smallest division to the spirit, an union will then take place.

To perform this experiment, put pounded sulphur into a matrass furnished with an alembic; suspend within it a cup or wide-mouthed bottle containing very strong ardent spirit, then put on the alembic, and adjust a phial to the beak; lute well the joinings, and heat the lamp.

The sulphur and spirit will now meet in a state of vapour, and the fluid which distils over will contain sulphur in solution.

To prove that sulphur is dissolved in the spirit, water may be added: the spirit will unite to the water, and the sulphur be precipitated.

This furnishes an instance that chemical attraction takes place only between the minutest parts of bodies. (See page 46.)

Experiment IV.

Sulphur is soluble in sulphuric ether.

Take one part of sulphur reduced to a fine powder, put it into a bottle, and pour over it eight of sulphuric ether; suffer the mixture to stand for some days, taking care to agitate it frequently. On decanting the supernatant fluid, the presence of sulphur may be proved, as stated before.

Experiment V.

Action of caloric on sulphur.

If sulphur be put in a crucible placed among burning coals, it will soon enter into fusion. This first fusion is liquid; but if it be kept longer over the fire it becomes tenacious, very thick, and dark coloured. When poured into water in this state, it will be soft as wax, and may be easily worked into any form between the fingers, instead of being solid or brittle, as sulphur is in common. Sulphur in this state may be employed with advantage as a paste for taking impressions from seals and engraved stones.

It is this property of sulphur of which Mr. Tassie has availed himself to furnish elegant impressions of antique gems.

It is supposed that sulphur rendered tenacious and coloured by fusion has combined with a portion of oxygen; and hence Fourcroy has given it the name of oxyd of sulphur. According to Dr. Thompson it contains 2.4 per cent. of oxygen. Dr. Thompson was unable to produce this change in the appearance of sulphur by heating it in a flat dish, where nothing impeded the volatilization, though he kept it melted in a glass capsule on sand heated to 250° for ten hours together.* But the change took place in a short time when a considerable quantity of sulphur was kept melted in a crucible; and the greater the quantity of sulphur employed the sooner the change took place, and the more complete it was effected. Dr. Irvine asserts that

* Nicholson's Journal, Oct. 1803, p. 102.

the shape of the vessel does not influence the thickening of sulphur by heat, provided enough of heat is employed;* and that the effect never fails to appear if the sulphur be exposed to the proper temperature necessary to produce this change. Dr. Irvine found that this thickening begins at 320° Fahr. and continues, and even increases, to the temperature of 530°, and even 550, at least.

If melted sulphur be withdrawn from the fire as soon as it is completely melted, and left to cool slowly, its parts assume a regular symmetrical arrangement, disposed in needles, which form a crystallization of sulphur.

If the vessel in which the sulphur is kept melting be covered with another vessel, and the air be excluded by luting, flowers of sulphur will be obtained in the upper vessel. As it seldom happens that there is not a small quantity of sulphur burnt in this process, the sublimed sulphur is usually in a slight degree acid; hence the acid should be removed by ablution.

COMBINATION OF SULPHUR WITH METALS.

Sulphur and iron have a great attraction to each other: the iron becomes of easy fusion and brittle by this motion.

Experiment I.

Formation of sulphuret of iron.

If a bar of iron be heated to *perfect whiteness* and then touched with a roll of sulphur, the two bodies combine, and drop down together in a fluid state, forming sulphuret of iron, a compound of the same nature as the native iron pyrites.

By this method a piece of iron rolled out very thin may be *apparently* melted in the hand, by putting it, when heated to whiteness, upon a thick piece of solid sulphur.

Remark....It is necessary that this experiment be performed under a chimney, or in a place where there is a current of air, to carry off the suffocating vapours.

If three parts by weight of iron filings and one of powdered sulphur be mingled together, and the mixture be introduced in a Florence flask, placed over the lamp furnace,

* Irvine's Essays on Chemical Subjects.

and gradually heated, it first begins to melt, but afterwards takes fire and burns vividly. The result is a brownish black sulphuret, weighing three ounces and six drachms.

Experiment II.

Sulphuret of arsenic.

If one part of sulphur and three of arsenic, both reduced to powder, be melted together in a covered crucible, a reddish yellow vitreous mass is obtained, which is a true sulphuret of arsenic. It is a perfect imitation of the native red sulphuret of arsenic, or realgar. It may be formed also by heating together the white acid of arsenic and sulphur.

Experiment III.

Sulphuret of lead.

To obtain this compound, let five parts of lead be fused, and add gradually, by little at a time, two parts of sulphur, taking care to cover the crucible carefully. The compound thus obtained is sulphuret of lead. It greatly resembles the native sulphuret.

Experiment IV.

Sulphuret of tin.

This sulphuret may be produced by fusing together three ounces of tin and one of sulphur. It crystallizes in leaves. Its colours is lead gray.

Experiment V.

Sulphuret of antimony.

Sulphur combines easily with antimony, and forms a compound greatly resembling the native sulphuret of antimony. To produce this sulphuret, let four parts of antimony and one of sulphur be hastily fused together in a covered crucible, and suffer the mass to cool slowly. It crystallizes in needles. Its colour is a brilliant gray.

Experiment VI.

Sulphuret of silver.

To obtain this sulphuret, let thin plates of silver and sulphur be laid alternately in a crucible; press them well together, and remove the crucible into a coal fire. As soon as the crucible has acquired a bright red heat the sulphur will have combined with the silver, and a true sulphuret of silver is the result. This sulphuret is of a deep violet colour: it is brittle, but capable of being cut with a knife. It is much more fusible than silver.

Experiment VII.

Sulphuret of bismuth.

If we heat together equal parts of bismuth and sulphur, both reduced to powder, in a crucible, the mixture fuses, and on being suffered to cool, a grayish black sulphuret of bismuth is obtained, beautifully crystallized in needles, and frequently tinged with the most brilliant deep blue and red colours. The crystallization is best effected by suffering the surface of the fused bismuth to cool and become solid, then piercing the solid crust, and letting the portion which is still liquid run off, whereby a kind of cavity is formed, lined with the most brilliant needles, and which, when sawed through longitudinally, presents a crystalline mass worthy of being placed in valuable collections amongst the most beautiful productions of art.

This sulphuret of bismuth is much more difficult of fusion than bismuth itself. Indeed, in forming the compound, we soon perceive that the fusion of the metal is retarded, and that, in order to fuse it, much more heat must be employed than would be necessary if the metal were by itself.

Experiment VIII.

Sulphuret of Copper.

(*Accension of sulphur and metals.*)

The union of sulphur with copper and other metals, at a low temperature, is attended with some remarkable phenomena. In order to exhibit this experiment, mix three

parts of copper filings and one of sulphur reduced to powder intimately together: introduce this mixture into a glass tube or Florence flask, and heat it gradually over a lamp or coal fire. After the mixture has been heated to a certain degree, it begins to swell, and a small ignited spark becomes first visible at the bottom of the glass vessel, which increases in size, exhibiting a combustion more rapid than that of iron and sulphur, mentioned before.

A society of Dutch chemists, consisting of Messrs. Dieman, Pacts, Van Troostwyk, and others, were the first who observed this phenomenon.

They introduced filings of copper with different proportions of sulphur into small glass phials, from which common air was excluded; being in some cases filled with carbonic acid gas, or nitrogen gas, and in others with water or mercury.

Whenever the phial was heated under any of these circumstances, the mixture began to swell, the metal always *became red hot*, and in some cases real inflammation took place, notwithstanding the exclusion of oxygen gas.

The proportions that produced most ignition or flame were forty parts of copper and fifteen of sulphur.

Tin and sulphur succeeded in the same proportion.

Lead and sulphur, the proportions being as forty-five of the former and fifteen of the latter.

Zinc and sulphur, in the same proportion, burned with explosion.

Mercury, antimony, and cobalt, could not be made to inflame with sulphur.

These experiments succeed equally well in the Torricellian vacuum.

COMBINATION OF SULPHUR WITH ALKALIES.

Alkalies and sulphur have a great affinity to each other in the dry as well as in the humid way.

Experiment I.

Preparation of sulphuret of potash.

If four parts of carbonate of potash be melted by a moderate heat, with three of sulphur, in a covered crucible,

a mass is obtained which after cooling exhibits a liver-brown colour. It is called *sulphuret of potash.*

It may also be produced by mixing four parts of sulphate of potash with one of charcoal powder, and exposing this mixture in a crucible to a bright red heat for about one hour.

Sulphuret of soda may be formed in a like manner, by melting together five parts of carbonate of soda, freed from its water of crystallization, with three of sulphur.

Experiment II.

Sulphuret of barytes.

If two parts of barytes and one of sulphur be mixed together, and the mixture be heated in a crucible for about half an hour, or till it fuses, a reddish yellow mass is obtained void of odour, which is sulphuret of barytes. It may likewise be obtained from the native sulphate of barytes. See Barytes.

Experiment III.

Sulphuret of strontia.

If three parts of strontia and one of sulphur be gradually heated till it melts, the compound obtained is sulphuret of strontia.

Sulphuret of strontia may also be produced by heating sulphate of strontia in contact with charcoal powder. See Barytes.

Experiment IV.

Sulphuret of lime.

That sulphur combines with lime may be proved by mingling one part of sulphur with two of powdered lime, and heating the mixture in a covered crucible for at least half an hour, or until no blue flame appears on the surface. The compound thus obtained is sulphuret of lime. In preparing this compound, care should be taken that both

the ingredients be very finely powdered, and intimately blended together. The mixture should not be rammed tight in the crucible, but loosely introduced; whereas, on the contrary, the whole is otherwise apt to be blown out of the vessel, as soon as the mixture becomes red hot.

Experiment V.

Preparation of sulphuret of ammonia.

Ammonia also combines with sulphur. Sulphuret of ammonia may be obtained in the following manner:

Two parts of finely powdered lime are put into a dry retort; upon this one part of muriate of ammonia, well mingled by trituration with one-third part of sulphur, is poured, and the whole mingled together by shaking. The charged retort is then placed in a sand-heat; a receiver, containing a little water, is adapted, and the distillation carried on very slowly. The fluid which passes over on increasing the heat is *sulphuret of ammonia*; it is of a deep yellow colour, a volatile and disagreeable odour, and fumes strongly in contact with air. In order to obtain sulphuret of ammonia very fuming, the first fluid which passes over must be kept separate; for it is only this which is smoking, by reason of its containing some uncombined ammonia. In other respects its properties are like the former combinations of sulphur with alkalies. Its volatility renders it capable of restoring oxydated metals to the metallic state, as may be evinced in the following

Experiment VI.

Dissolve some crystallized nitrate of silver, free from excess of acid, in a sufficient quantity of distilled water; dilute the solution with water, till writings performed with it on paper are invisible when dry. If this writing be exposed to the vapour of the sulphuret of ammonia, it will become visible with the brilliancy of silver.

Rationale....The sulphuret of ammonia gives out sulphurated hydrogen gas at the ordinary temperature of the atmosphere: on coming into contact with the solution

of silver, the hydrogen attacks the oxygen of the silver and forms water, and the metal becomes revived, which then unites with the ammonia and sulphur, in order to form a sulphurated ammoniuret of silver.

COMBINATION OF SULPHUR WITH EARTHS.

Experiment I.

Sulphuret of magnesia

Is best prepared in the following manner: one part of charcoal powder is to be mixed with six of sulphate of magnesia; the mixture is then reduced to dryness, and ignited gradually.

Rationale....Sulphate of magnesia consists of sulphuric acid and magnesia. At a high temperature the sulphuric acid becomes decomposed by the charcoal which unites to its oxygen in order to be converted into carbonic acid gas, and sulphur is produced. The carbonic acid gas flies off, and the sulphur unites to the magnesia.

Care must be taken not to ignite this sulphuret too much, for the sulphur seems to adhere to the magnesia very feebly.

In the same manner alumine may be united to sulphur.

Experiment II.

Sulphuret of alumine.

See Pyrophorus.

COMBINATION OF SULPHUR WITH CARBON AND PHOSPHORUS.

Till lately it was supposed that sulphur does not combine with carbon; but Messrs. Desormes and Clement, two French chemists, who have paid particular attention to the properties of carbon, have lately announced a method of combining them in the following manner.

Experiment I.

Fill a porçelain or earthenware tube with well-burnt charcoal, and make it pass through the openings of the universal furnace (*see universal furnace*) in such a way that one end shall be considerably elevated above the other. To the other end lute a wide glass tube, of such a length and shape that its end can be plunged to the bottom of a bottle of water. To the elevated extremity of the tube adapt another glass tube filled with small pieces of sulphur, and secured at the farther end, so that the sulphur may be pushed forwards by means of a wire, without allowing the inside of the tube to communicate with the external air. Heat the porcelain tube, and consequently the charcoal which it contains, to redness, and continue the heat till air bubbles cease to come from the charcoal; then push the sulphur slowly, and piece after piece into the earthen tube. A substance will then soon be delivered by the glass tube, which condenses under the water in the bottle into a liquid. This liquid is a combination of carbon and sulphur, and hence it has been called *carburet of sulphur.*

This carburet of sulphur is transparent and colourless when pure, but very frequently it has a greenish yellow tinge. Its taste is pungent, and its odour very peculiar and penetrating. Its specific gravity is 1. 3. It does not mix with water. When put into the receiver of an air-pump, and the air exhausted, it rises in bubbles through the water, and assumes the form of a gas. The same change takes place when it is introduced into the top of a barometer tube; but it is again condensed into a liquid, when the tube is immersed under mercury.

Carburet of sulphur burns easily, like alcohol and many other fluids. During the combustion it emits a sulphureous odour. Sulphur is deposited, and charcoal remains behind. When a little of it is put into a bottle filled with oxygen gas, it dissolves in it, and assumes the gaseous state. If a burning taper be applied to the mouth of the bottle, this mixture burns instantaneously, and with an explosion so violent as to endanger the vessel. It as-

sumes the gaseous form in the same way when placed in contact with atmospheric air. This mixture does not detonate when kindled, but burns quietly. Carburet of sulphur dissolves phosphorus readily; it dissolves likewise a small portion of sulphur, but it has no action whatever on charcoal.*

The combination of sulphur with phosphorus will be considered in the next part.

* Ann. de Chim. 42, 136.

PHOSPHORUS.

PART XII.

SECT. I.

NATURAL HISTORY OF PHOSPHORUS.

PHOSPHORUS is the next simple body we have to consider; it has never been found pure in nature. It is always met with united to oxygen, or in the state of phosphoric acid: in that state it exists very plentifully, and is combined to different animal, vegetable, and mineral substances.

PHYSICAL PROPERTIES OF PHOSPHORUS.

Phosphorus is a flesh-coloured or yellowish semi-transparent substance, of the consistence of wax, but brittle during frost. In atmospheric air it is luminous at common temperatures, without emitting heat. It has a rough disagreeable taste, and its odour resembles that of garlic. Its specific gravity is 2.033, water being 1.000. Phosphorus crystallizes in laminæ, in needles, or elongated octahedra. Exposed to the light it becomes covered with a crust, which is first white, next orange, and at last red. It becomes liquid at a temperature of 99° Fahr. It has a strong attraction for metallic oxyds. It takes fire spontaneously, and burns rapidly in the open air at 122° Fahr. with a brilliant white flame, and becomes converted into phosphoric acid. It is volatilized at 554° Fahr. It is soluble in caustic alkalies by the assistance of heat. Expressed and essential oils take up a small quantity, and

are rendered luminous. Sulphuric ether, nitric ether, and ardent spirit, dissolve it sparingly in the cold. It combines with lime, strontia, barytes, sulphur, charcoal, and with metals. It is soluble in hydrogen gas, and decomposes nitric acid and metallic solutions. It acts strongly, and frequently like poison, on living animals.

METHODS OF OBTAINING PHOSPHORUS.

For some time phosphorus was made in very inconsiderable quantities, and by a tedious and disagreeable process, consisting in evaporating considerable quantities of urine, and decomposing them by various means.

The following processes now employed are more easy and expeditious.

1. GIOBERT'S PROCESS.

According to this method phosphorus may be obtained without any offensive preparation. It consists in pouring a concentrated solution of nitrate of lead, by a little at a time, into a quantity of urine until no more cloudiness is produced by a further addition of the solution. The mixture is then to be diluted with soft water, and suffered to stand undisturbed: when the precipitate has fully subsided, the clear fluid is to be separated. The precipitate is formed into a paste with charcoal powder, the mass dried gradually in an earthen pan, and submitted to distillation.

RATIONALE....The phosphoric acid of the urine unites to the lead of the nitrate of lead, and the nitric acid joins to the ammonia and soda of the urine; hence phosphate of lead and nitrate of soda and ammonia are formed. The former, being insoluble, falls to the bottom, and the latter salt remains in the super natant fluid. On adding charcoal to the phosphate of lead, and exposing it to a high temperature, the union is again broken: the phosphoric acid becomes decomposed, its oxygen unites to the charcoal and forms carbonic acid gas, which flies off during the distillation: the phosphorus appears in its simple state, and the metal is left behind in the retort, together with the super-abundant quantity of charcoal.

2. NICOLA'S PROCESS.

Take a quantity of bones of adult animals, burn them to whiteness in an open fire, and reduce them to a fine powder. Upon three pounds of this powder, after having been put into a mattrass, there may be poured one pound of concentrated sulphuric acid of commerce; four or five pounds of water must be afterwards added by degrees, to assist the action of the acid. During the whole process the operator must place himself and the vessel so that the fumes of the mixture may be blown from him. The whole is then to be left in a gently heated sand-bath for about twelve hours or more, taking care to supply the loss of water which happens by evaporation. The next day a large quantity of water must be added, the clear liquor afterwards decanted, and the rest strained through a cloth or sieve. The residuary matter is to be edulcorated by repeated affusions of cold water, till it passes tasteless. The water which has been used to wash out the adhering acid is mixed with the before decanted or strained liquor, and the whole fluid is gradually evaporated in a flat earthen basin to the consistence of syrup. It is then to be mixed with four ounces of charcoal powder, and submitted to distillation in an earthen retort. Instead of applying a receiver, the neck of the retort may be immersed in a basin of water to a small depth, and the phosphorus as it comes over will fall in drops to the bottom.

Rationale....The first part of the process consists in destroying the gelatine of the bones, by the action of heat. They then consist of phosphate of lime, mixed with a very little carbonate of lime. In the second part of the process, the phosphate of lime is decomposed by the sulphuric acid: this decomposition is, however, only partial. The sulphuric acid combines with part of the lime, and forms an insoluble sulphate of lime. The phosphoric acid, separated from that portion of lime, immediately combines with the rest of the phosphate, and produces a super-phosphate of lime, which is no further decomposable by sulphuric acid.

The super-phosphate of lime thus formed is soluble in water, but as the sulphate of lime with which it is mixed concretes into a very thick or solid mass, it is in

some measure defended from the action of the water; hence a large quantity of water is necessary to dilute the mass. It is from this super-phosphate of lime that the phosphorus is obtained. The charcoal at an elevated temperature takes the oxygen from the phosphoric acid, and hence the phosphorus passes over.

Three pounds of bones yield 1½ oz. and 30 grs. of phosphorus, if the process be well conducted.

METHOD OF PURIFYING PHOSPHORUS.

Phosphorus obtained in either manner is of a dirty blackish colour, and soiled, with a certain quantity of charcoal and oxyd of phosphorus, which gives it that appearance. In order to purify it, it must be put into a piece of chamois leather, and closely tied up in it. The whole is then immersed in a vessel of hot water; the phosphorus melts, and may be pressed through the leather, taking care to keep it under the water.

It is better, however, to purify phosphorus by a second distillation.

Dr. Higgins purified it by means of hydrogen gas.*

METHODS OF MOULDING PHOSPHORUS INTO CYLINDERS.

In order to form phosphorus into sticks, a funnel with a long neck may be used, the lower orifice of which is closed with a cork: the funnel is then to be filled with water, and phosphorus put in it; and this being plunged into boiling water, the heat communicated to the funnel melts the phosphorus, which runs into the neck, and acquires that form. The funnel is then removed into a vessel of cold water; and when it is thoroughly cooled, the cork is taken out and the phosphorus thrust out of its mould with a piece of wood, and then preserved in water.

Pelletier invented another method, which is as follows: Take a few tubes of any length, the apertures of which are of such a size that they can be exactly closed with the extremity of the finger. Melt the phosphorus in boiling

* Minutes of the Society for Philosoph. Exper. &c.

water, and apply to it one of the ends of the tube, while you hold the other in your mouth; make a short inspiration, that the phosphorus may ascend a little way in the tube; stop the inspiration when the phosphorus has risen a sufficient height, and close the extremity of the tube with the fore finger, and immerse it in a basin of cold water. The phosphorus will soon become fixed, and by a slight shake may be separated from the tube.

The combustibility and luminous property of phosphorus have given birth to various amusing experiments; which we shall insert, for they are well calculated to evince some of its characteristic properties in a pleasing manner,

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF PHOSPHORUS.

Experiment I.

Phosphorus burns at the common temperatures of the atmosphere.

LUMINOUS CHARACTERS.

THAT phosphorus burns at the usual temperature is obvious by writing with a cylinder of it upon black paper, or upon any other smooth surface. The writing appears luminous in the dark, as if on fire: the fiery appearance vanishes by blowing on the object, but becomes visible again in a few seconds.

If the writing is performed upon the purple coloured paper of this country, the traces appear red in the day-light after the luminous appearance has ceased.

Rationale....The phosphorus has been converted into phosphoric acid, which changes the blue vegetable colour of the paper to red: the light evinces the combustion of the phosphorus.

REMARK....It is necessary to place the cylinder of phosphorus in a quill or metallic pencil case, in order that it may be removed from the hands, if it should take fire; which may happen, particularly in hot weather. A cup or basin of water should likewise be near at hand to plunge it into, to prevent accidents.

EXPERIMENT II.

Phosphorus takes fire by the application of a very gentle heat.

Introduce a few pieces of phosphorus, of the size of a pin's head, into tow or cotton, and wrap the cotton round a phial, or glass cylinder; on filling the phial with hot water, the phosphorus inflames and sets fire to the cotton.

EXPERIMENT III.

Accension of phosphorus by friction.

Fold up in a piece of brown paper a few grains of phosphorus, and rub it against any hard body, or between the paper itself; the phosphorus inflames and sets the paper on fire.

A few grains of phosphorus rubbed in a mortar with iron filings, take fire instantly.

RATIONALE....The friction applied in these experiments raises the temperature of the phosphorus; it then attracts the oxygen from the atmosphere rapidly, in order to become converted into phosphoric acid, and the heat and light both of the phosphorus and oxygen gas are set free.

REMARK....It is curious that written paper inflames more readily than paper which has not been written upon. Straw and wood are extremely difficult to be fired by burning phosphorus, they become only converted into charcoal; but sulphur, cotton, ardent spirit, ether, and essential oils, take fire by it readily.

EXPERIMENT IV.

A phosphoric fire-bottle.

Take a small thin phial, heat it gradually in a ladle full of sand, and introduce into it a few grains of phosphorus;

the phial is then to be loosely stopped, and left undisturbed for a few minutes: small quantities of phosphorus are thus repeatedly added until the phial is full. Another method of preparing this phosphoric bottle consists in heating two parts of phosphorus and one of lime mixt together in a loosely stopped phial for about half an hour.

To use this fire-bottle, a common match or small bit of wood tipped with sulphur is introduced into the phial, turned round and quickly drawn out, which causes the phosphorus to take fire as soon as it comes out of the bottle.

Phosphoric fire-bottles may also be prepared by adding to melted phosphorus under water one sixteenth of sulphur. This compound is so inflammable that if a minute quantity be taken out of the bottle with a match, and rubbed upon a cork, it inflames instantly, and fires the match. (*See Appendix No.* 11.)

Experiment V.

Phosphoric tapers.

Take a glass tube, about four inches long and one line wide, closed at one end. A small quantity of phosphorus is to be introduced into the tube, and pushed to its extremity with an iron wire, after which a taper covered at one end with wax is put into it; the open end of the tube is then hermetically sealed, and the other plunged into hot water. The phosphorus melts and fixes as it cools upon the taper. A line is then drawn by means of a diamond or file at one-third of the tube. To use these tapers, the tube is broken at the marked line; and when it is quickly drawn out, it takes fire, and burns rapidly.

Experiment VI.

Phosphorized ether.

If phosphorus be dissolved in rectified sulphuric ether, and poured into a decanter, at the bottom of which is a little water, a brilliant light is disengaged, which passes with a serpentine motion along the surface of the fluid.

The air within the vessel becomes luminous, and remains for some time in this state.

1. If the decanter be unstopped, and air blown into it, the luminous vapour disappears: but if the mixture be again agitated, several luminous points are seen at its surface, the air of the decanter becomes again phosphorescent, and this may be renewed until the whole of the ether has been decomposed.

2. If a feather be dipped in water, and in this state be plunged into phosphorized ether, at the moment of contact of the two fluids, a sudden light spreads through the air, and very perceptible flashes are seen (in a dark place) to issue from time to time out of the mouth of the phial.

3. When a lump of fine loaf-sugar is wetted with phosphorized ether, and thrown into a basin of water, the whole of the surface will be illuminated; by gently blowing it, beautiful undulations are formed, greatly resembling the fiery appearance of the sea.

All these experiments with phosphorated ether succeed best if the water be a little warm.

RATIONALE....The phosphorized ether is decomposed on coming in contact with a large quantity of water; the water unites with the ether; the phosphorus being then presented to the air, burns, and exhibits the luminous appearance.

Phosphorized ether is best prepared by suffering sulphuric ether to stand for some weeks over a considerable quantity of phosphorus in a well-stopped phial.

EXPERIMENT VII.

Liquid Phosphorus.

When phosphorus is dissolved in oils, it forms what is called liquid phosphorus. The best method of preparing it, is to heat very gently one part of phosphorus with six of oil of olives. The oil thus charged with phosphorus must be kept in a bottle, well corked. It may also be prepared by rubbing in a mortar one part of phosphorus with one-sixteenth of sulphur and a small quantity of olive oil, until a perfect homogeneous mass is obtained, and then adding gradually more oil to effect a solution. Liquid phosphorus has the property of becoming luminous in the

dark as soon as the phial containing it is unstopped, and opaque again when the phial is corked. It may serve for showing the hour of the night, by holding a pocket-watch against the bottle when unstopped. It may likewise be used for forming luminous writings, or drawings, by means of a small brush. It may also be rubbed on the face, hands, &c. to make them appear luminous, without injury.

Liquid phosphorus may likewise be prepared by triturating phosphorus in a stone mortar, with oil of cloves. This method is expensive.

Experiment VIII.

Accension of phosphorus by means of sulphuric acid and water.

Melt over a slow fire, in a cup, gallipot, or phial, containing a table-spoonful of water, a small quantity of phosphorus: as soon as the water boils, pour into it about one drachm of concentrated sulphuric acid. In a few minutes the surface of the mixture becomes filled with luminous vapours, a considerable ebullition takes place, accompanied with a hissing noise, which increases gradually until the mixture takes fire, with a smart explosion. Little fire-balls and stars will be thrown out in all directions, and the whole will boil very high.

Rationale....This accension of phosphorus is owing to the heat evolved by the mixture of the acid and water.

Remark....To perform the experiment with safety, the vessel containing the water and melted phosphorus should be fastened to the end of a long stick, in order that the operator may be at a sufficient distance when the explosion takes place, as it frequently happens that the vessels are dashed to pieces the moment the mixture is made, and the whole is thrown about to a considerable distance.

Experiment IX.

Phosphorus precipitates copper in a metallic state.

Put into a concentrated solution of nitrate, or sulphate of copper, a cylinder of phosphorus, and leave it undisturbed for at least twenty-four hours. The phosphorus

will precipitate the copper, and by that means become covered with a stratum of brilliant metallic copper.

RATIONALE...The phosphorus has a stronger affinity for oxygen than copper has; it therefore deoxydizes the solution of this metal, and the copper re-appears in its metallic state.

M. Schnaubert has lately examined the action of phosphorus in metallic solutions,* from which it appears that the solutions of gold, silver, mercury, lead, tin, and manganese, are all deoxydized by phosphorus, and that, when reduced, in many cases again unites to another portion of the phosphorus, forming phosphurets, as is the case in the deoxydizement of the solutions of silver, mercury, and tin.

EXPERIMENT X.

A luminous fluid which throws out flashes of light.

Water boiled with a little phosphorus for a few minutes, and preserved in a well-corked phial, becomes luminous in the dark. Long cylinders of glass, filled two-thirds with this solution a little warmed, and then agitated, discharge flashes of light in all directions into the air.

RATIONALE....Part of the phosphorus is dissolved by the water, and remains in combination with it so long as this fluid is at rest, but becomes disengaged when the water is agitated; it then burns, and exhibits the luminous appearance.

EXPERIMENT XI.

Phosphorized mercury.

May be prepared by dissolving phosphorus by trituration in a mortar, in as little oil of cloves as possible, and then uniting this mixture to mercury, by a continual agitation.

Long cylinders filled with this compound become luminous when shaken in the dark.

RATIONALE....A simple spontaneous combustion of minutely divided phosphorus.

* Gœtling's Faschenbuch, 1804, v. i. p. 99.

COMBINATION OF PHOSPHORUS WITH METALS.

Experiment I.

Phosphuret of arsenic.

Phosphuret of arsenic may be obtained in the following manner: Take two parts of metallic arsenic, reduce it to an impalpable powder, put it into a Florence flask, and pour over it six of water, and then add one of phosphorus. Place the flask over the lamp-furnace, and apply a gentle heat for at least three hours, taking care to supply the water as it evaporates. The phosphuret of arsenic thus obtained is of a brilliant gray colour; it may be freed from the adhering or superfluous phosphorus, by squeezing it through a fine muslin, under the surface of heated water.

Experiment II.

Phosphuret of Copper.

To obtain phosphuret of copper, let the finest copper wire that can be obtained be coiled up into a ball, and heated to redness in a crucible, and then let fall on it pieces of phosphorus, until the copper melts. The phosphuret thus obtained is of a yellowish white colour: on being broke, it exhibits a crystalline appearance. It soon loses its lustre on exposure to the air, and becomes black.

Experiment III.

Phosphuret of gold.

This compound may be obtained in a similar manner, by letting fall pieces of phosphorus on fine gold wire, heated to whiteness, expeditiously covering the crucible the moment the phosphorus has reached the gold wire. Phosphuret of gold is of a brass-yellow colour. It is very brittle, and exhibits, on being broken, needle-shaped crystals.

Experiment IV.

Phosphuret of iron.

To obtain this phosphuret, let fine iron wire be heated as before, and drop into the crucible pieces of phosphorus of the size of a pea, until an union is effected, which may be known by the wire melting down suddenly. The properties of this phosphuret have not been examined.

Experiment V.

Phosphuret of lead.

Phosphuret of lead may be prepared by melting lead in a crucible, and then adding to it phosphorus in small quantities at a time. By the first addition of phosphorus, the lead acquires consistence; but on increasing the heat, and continuing the addition, the whole becomes again fluid, which is the criterion that the process is at an end. It is of a silver white, but soon tarnishes on exposure to air.

Experiment VI.

Phosphuret of nickel.

Phosphuret of nickel may be formed by melting nickel, and letting fall on it phosphorus. The union is very difficult to be obtained: one part of nickel requires about eleven of phosphorus. The phosphuret obtained fuses more easily than nickel. It is a white crystalline substance; its properties have not yet been examined.

Experiment VII.

Phosphuret of silver.

Phosphuret of silver is best prepared by heating to redness, in a crucible, fine silver, rolled out as thin as writing paper, and then letting fall on it phosphorus, in small quantities at a time, until the fresh added portion of phosphorus combines with the ignited silver. Phosphuret of silver is of a white colour, and of a granulated texture. It is very hard, and soon tarnishes on exposure to air.

Experiment VIII.

Phosphuret of cobalt

May be formed by heating to redness, in a crucible, cobalt, broken into pieces of the size of a split pea, and then adding to it gradually pieces of phosphorus of the same size, until the cobalt fuses. Phosphuret of cobalt is of a reddish-white colour: it is very brittle, and fuses more easily than cobalt.

COMBINATION OF PHOSPHORUS WITH ALKALIES.

Experiment I.

Preparation of phosphuret of lime.

Take an earthen or glass tube, about one foot long and three-quarters of an inch in diameter, and closed at one end; put into this one ounce of phosphorus, cut into pieces of the size of a pea, and freed, by means of blotting-paper, from the adhering water; then introduce into the tube three ounces of fresh burnt lime of the size of split peas, and stop the other opening of the tube loosely with a chalk stopper, to prevent the access of air. Having done this, heat to redness *that part of the tube which contains the lime*, by means of charcoal: when the lime may be supposed to be ignited, apply heat to the part containing the phosphorus, so as to sublime it, and to bring the vapour of it into contact with the ignited lime. The lime and phosphorus will now unite and form a mixture of a reddish brown colour, which is phosphuret of lime. This preparation has the property of making fire rise out of water, when small pieces of it are dropt into it.

Rationale....The phenomenon is owing to a decomposition of water at the common temperature, which shall be more fully treated on under the article *phosphorized hydrogen gas.*

Remark....If a glass tube be made use of for preparing phosphuret of lime, that part of the tube which is heated (which may conveniently be done by passing it through the universal furnace, or through a chafing dish, filled with ignited charcoal) should be coated with clay, or

loam, in order to secure it from breaking during the process.

Phosphuret of lime may also be prepared, according to Von Mons,* in the following manner:

Fill a small glass mattrass two-thirds with carbonate of lime in powder: put it into a sand-bath, and expose it to a heat sufficient to drive off the carbonic acid. Towards the end of the process introduce gradually a third part of phosphorus, taking care to keep the lime in a red heat. The phosphorus melts, but is prevented from burning by the remains of carbonic acid which is disengaged from the lime. When the whole of the phosphorus is introduced, shut up the mattrass with a stopper provided with a valve to let gas escape, but permit none to enter, and let the fire be immediately withdrawn. When quite cold the phosphuret is to be put in a dry bottle.

Experiment II.

Phosphuret of barytes.

To prepare phosphuret of barytes, introduce into an earthen tube, closed at one end, first, one part of phosphorus, and then add two of fresh prepared barytes, and proceed as directed before. Phosphuret of barytes is of a brownish yellow colour: it also causes phosphorized hydrogen gas to be evolved when thrown into water.

Experiment III.

Phosphuret of strontia.

Phosphuret of strontia may be obtained in a similar manner.

COMBINATION OF PHOSPHORUS WITH CARBON.

Phosphorus is also capable of combining with carbon, or rather with charcoal. This compound, which has received the name of *phosphuret of carbon*, was first examined by Mr. Proust. It is the red substance which remains behind when new made phosphorus is strained through chamois

* Journal de Chim. iii. 75.

leather. In order to separate from it a small quantity of phosphorus, which it contains in excess, it should be put into a retort, and exposed for some time to a moderate heat. What remains behind in the retort is the pure phosphuret of carbon. It is a light flaky powder, of a lively orange red, without taste or odour. When heated in the open air, it burns rapidly, and a quantity of charcoal remains behind. When the retort in which it is formed is heated red hot, the phosphorus comes over, and the charcoal remains behind.*

This phosphuret of carbon may also be obtained by putting a few grains of phosphorus in a silver spoon, and then heating the spoon, to cause the phosphorus to burn. After the combustion of the phosphorus has ceased, a red trace will be observed in the spoon, which is carburet of phosphorus; hence the pure phosphorus always contains a portion of this compound, from which it cannot be freed by any process yet known.

* Ann. de Chim. xxxiv. 44.

DIAMOND,

OR

PURE CARBON.

PART XIII.

SECT. II.

NATURAL HISTORY OF DIAMOND.

IT appears at first extraordinary that the diamond, which has been so long placed in the rank of precious stones, or crystallized gems; that the diamond, one of the hardest bodies in nature, should at present be reckoned in the class of combustible bodies, next to sulphur and phosphorus. It is nevertheless entitled to this place, as will be seen presently.

The diamond, which was well known to the ancients, is principally found in the western peninsula of India, on the coast of Coromandel, in the kingdoms of Golconda and Visapour, in the island of Borneo, and in the Brazils.

Diamonds are generally found bedded in yellow ochre, or dispersed among rocks of free-stone or quartz, and sometimes in the beds of running waters. It is not known whether there is any rock where the diamonds are found which has some of the properties of these bodies, or which has served as a matrix for their formation. They do not lie in clusters; but are always found detached, at a greater or less distance. Those mines which yield large diamonds frequently do not contain above one in a quarter of an acre; those that yield small diamonds contain a greater number in the same space. There are about twenty-three

diamond mines in Golconda, and fifteen in Visapour. The depth of these mines is commonly three or four fathoms. The miners can seldom dig deeper, on account of the water, which they have no method of removing. In one of the Golconda mines, they are obliged to dig through rock five or six feet deep, before they come to the stratum of earth in which the diamonds are deposited. They work through this rock with great difficulty, as they seem to be altogether unacquainted with the use of gunpowder in mining. They, however, in some measure supply its place by lighting a large fire on that part of the rock through which they intend to pass: when the heat has penetrated the rock to a sufficient depth they split it, by throwing cold water upon it. Diamonds, when taken out of the earth, are incrusted with an exterior earthy covering, under which is another, consisting of carbonate of lime.

This earthy incrustation covers them so perfectly, that it is with the utmost difficulty that they can be distinguished from an indurated iron ore. It adheres so strongly to them, upon many occasions, that it cannot be got off but by grinding or rubbing them against one another. From this, as well as from the foreign matter that is frequently found in the centre of diamonds, it would appear that they were once in a soft or fluid state, or that it was not till long after their first formation that they acquired that hardness for which they are so much valued. In consequence of the diamond, when bedded in the earth, having so little of the lustre by which it is easily distinguished in its polished state, it is necessary to examine the earth in which they lie with the utmost attention. In order to render this as easy as possible, the lighter earths, and those parts that approach in quality to common mould, are removed by agitating the whole in water, and pouring off immediately the muddy fluid. As the diamond is among the heaviest of the earthy and stony substances, there is little danger of its being carried off in this manner. Those parts which are not carried off by the water are dried in the sun, and carefully examined. Every thing that has the smallest resemblance to the diamond is rubbed against the common kinds of stone. If it does not discover itself to the satisfaction of the miners by this method, they strike it with violence against a hard body, and sometimes with the iron instrument with which

they work. By this imprudent method many of the finest diamonds have such cracks or flaws in them that their value is greatly diminished.

In the Brazils it is supposed that diamonds might be obtained in greater quantities than at present, if the sufficient working of the diamond mines was not prohibited, in order to prevent that diminution of their commercial value which a greater abundance of them might occasion.

REMARK....Brazilian diamonds are in commercial estimation inferior to the oriental ones.

In the rough, diamonds are worth two pounds sterling the carat, or four grains, provided they are without blemish. The expence of cutting and polishing amounts to about four pounds more. The value, however, is far above what is now stated when they become considerable in size.

The usual method of calculating the value of diamonds is by squaring the number of carats, and then multiplying the amount by the price of a single carat: thus, supposing one carat to be £2, a diamond of 8 carats is worth £128, being $8 \times 8 \times 2$.

The famous Pigot diamond weighs 188$\frac{1}{8}$ grains.

The following very remarkable diamonds, with regard to size and value, may be noticed.

1. That which is in the possession of the Great Mogul; its weight is 279 carats, and is valued at 6 millions of florins, about £540,000 sterling.

2. That belonging to the Grand-duke of Tuscany weighs 139 carats, and is valued at one million of florins, about £90,000 sterling.

3. That in the possession of the King of Portugal weighs 215 carats.

4. The diamond which the Stadtholder Pitt sold to the Duke of Orleans, for the King of France, for 1,500,000 livres. Its weight is 547 grains; and there was one in the crown of the late king of France, of 106 carats.

5. Mr. Gregor Saffraz, of the family of Gogia Minarian, was in possession of a diamond from the East Indies, weighing 779 grains. And,

6. The rough diamond from Brazil, in the possession of the King of Portugal, weighs 1680 carats. This is the largest diamond known.

PHYSICAL PROPERTIES OF DIAMOND.

Diamond is always crystallized; but sometimes so imperfectly, that at first sight it might appear amorphous. The figure of the diamond when perfect is an eight-sided prism. There are also cubical, flat, and round diamonds. It is the oriental diamond which crystallizes into octahedra, and exhibits all the varieties of this primitive figure. The diamond of Brazil crystallizes into dodecahedra.

The texture of the diamond is lamellated, for it may be split or cleft with an instrument of well-tempered steel, by a swift blow in a particular direction. There are, however, some diamonds which do not appear to be formed of *laminæ*, but of twisted and interwoven fibres, like those of knots in wood. These exceed the others greatly in hardness; they cannot be cut or polished, and are therefore called by the lapidaries DIAMONDS OF NATURE.

The diamond is one of the hardest bodies known. It resists the most highly tempered steel file, which circumstance renders it necessary to attack it with diamond powder. It takes an exquisite and lasting polish. It has a great refractive power; and hence its lustre, when cut into the form of a regular solid, is uncommonly great. It sparkles with all the splendour of the rainbow, principally when its effects are multiplied by cutting, and the number of the polished facets with which it is enclosed. The usual colour of diamonds is a light gray, often inclining to yellow, at times lemon colour, violet, or black, seldomer rose-red, and still more rarely green or blue, but more frequently pale brown. The purest diamonds are perfectly transparent. The colourless diamond has a specific gravity which is in proportion to that of water as 3.512 to 1.000, according to Brisson. This varies, however, considerably. When rubbed it becomes *positively* electric, even before it has been cut by the lapidary.

Diamond is not acted upon by acids, or by any chemical agent, oxygen excepted; and this requires a very great increase of temperature to produce any effect. It then burns with flame and decrepitation.

The diamond burns by a strong heat, even in common air, with a sensible flame, like other combustible bodies,

attracting oxygen, and becoming wholly converted into carbonic acid gas during that process.

It combines with iron by fusion, and converts it, like common charcoal, into steel; but diamond requires much more oxygen to burn in than common charcoal does, and even then it consumes but slowly, and ceases to burn the instant its temperature is lowered.

It is considered by modern chemists as **PURE CRYSTALLIZED CARBON.** (*See Appendix No.* 12.)

SECT. II.

PROOFS OF THE COMBUSTIBILITY OF DIAMOND.

The combustibility of the diamond is a phenomenon sufficiently interesting to induce us to give an extract of the principal experiments which have served to advance our knowledge upon this subject.

The emperor Francis I, exposed to a vehement heat the value of six thousand florins in diamonds and rubies; the diamonds disappeared, but the rubies remained unaltered. These experiments were repeated; and it was ascertained that the diamond lost its polish, scaled off, and was dissipated.

The grand duke of Tuscany, in 1694, caused experiments to be made by Averoni and Targioni, by the mirror of Tschirnhausen, and the diamond disappeared in a few minutes.

These experiments were repeated by the French chemists, Darcet, Cadet, Lavoisier, &c. with equal success. The details of their experiments may be seen in the volumes of the Academy of Sciences, and the Journal de Physique for the year 1772.

Macquer took notice that the diamond dilated, swelled, and burnt with a blue flame. Ladriana* mentions an experiment, in which the diamond was fixed to the end of a small iron wire, which was heated red hot, and plunged into a vessel filled with oxygen gas. The combustion of the iron communicated itself to the diamond,

* Annales de Chim. tom. xi. p. 156.

which burnt in this gas with a very bright flame. This experiment, however, did not succeed with the diamond of Brazil.

Lavoisier and Cadet proved that the combustion of the diamond, in close vessels, like all other combustible bodies, ceased as soon as the oxygen was exhausted, and that it only burnt in proportion to the oxygen presented to it.

De Saussure burnt a diamond by means of the blow-pipe.

But as the sole object of all the former experiments was to ascertain the combustibility of the diamond, no attention was paid to the products it afforded during the process; and it still remained to be determined whether the diamond was a distinct substance, or one of the known inflammable bodies. No attempt was made to decide this question, till Lavoisier, in 1777, undertook a series of experiments for this purpose. He exposed the diamond to a large lens, and was thus enabled to burn it in a close glass vessel. He observed that the air, in which the diamond had been burnt, became absorbed by water; that it disturbed lime-water; and that the precipitate obtained was soluble in acids with effervescence.

Carbonic acid had therefore been formed. As nothing was present but diamond and oxygen, and as carbonic acid gas consists of charcoal, oxygen, and caloric, the diamond and oxygen must have been converted by caloric into the state of carbonic acid gas; and hence the diamond must have been charcoal.

The diamond is therefore a combustible body, which burns in the same manner in oxygen gas as charcoal does. This strict and accurate consequence is deduced from all the experiments which can be imagined to acquire a perfect demonstration. But that the diamond was *charcoal in its pure and crystallized state* was left to the determination of modern chemists.

Guyton Morveau applied the solar heat, by means of a great lens, to a diamond placed in a china cup, and surrounded in a proper apparatus, with a confined quantity of oxygen gas.

In one experiment the diamond exhibited, first, a black point at the angle directly struck by the solar rays; after this, it soon became completely black, and of a coaly appearance; the instant afterwards, brilliant and as it were

boiling points were distinctly perceived on the black ground. It now began to diminish in size, and in a short time no more than one-fourth was remaining. It was then withdrawn. It was without any marked sharp angles or edges, but still very white, and of a beautiful transparency. The diamond was a second time heated with the solar rays, and in twenty minutes entirely consumed without any residue. During this operation the same phenomena were observed.

A solution of barytes was then introduced over the mercury, confining the air in which the diamond had been consumed. It became immediately milky, the volume of the gas diminished, and carbonate of barytes was formed.

In this process a greater quantity of carbonic acid was obtained than would have been produced had the diamond been in the same state as common charcoal: for one part of charcoal absorbs during combustion 2.527 of oxygen, and produces 3.575 of carbonic acid; but one part of diamond absorbs somewhat more than four parts of oxygen, and produces five of carbonic acid.

The diamond of which Guyton effected the complete combustion was a native octahedral crystal. It burned in a temperature of about 90 pyrometrical degrees, which in the scale of Wedgwood constitutes a difference of from 183° to 1765°.

We are likewise indebted to Dr. Smithson Tennant for some excellent experiments on the nature of the diamond. His paper, of which we shall give an abstract, is in the Philosophical Transactions for 179[illegible]. Dr. Tennant has taught us a method of effecting the combustion of the diamond in a much easier manner than that stated above. He has proved that, by means of nitrate of potash, the combustion may be accomplished in a moderate heat.

The Dr. procured a tube of gold, which having one end closed, served as a retort, to which a glass tube was adapted, in order to collect the air produced. To be certain that the gold vessel was perfectly closed, and that it did not contain any thing which could occasion the production of carbonic acid, some nitrate of potash was heated and decomposed in it, and afterwards washed out with water. The solution was examined, but did not exhibit any appearance of carbonic acid.

The diamond was then burnt in this vessel by means of nitrate of potash. When it was thus destroyed, the substance which remained precipitated lime from lime-water; and on the addition of acids, afforded carbonic acid gas and nitrous gas, and therefore consisted of nitrate of potash partly decomposed, and carbonate of potash.

In order to estimate the quantity of carbonic acid which might be obtained from a given quantity of diamonds, two grains and a half of small diamonds were put into the golden tube, with a quarter of an ounce of nitrate of potash, the whole was then kept in a strong red heat for about an hour and a half. After the tube had grown cold again, the contents were dissolved in water, consequently the diamonds had been destroyed.

In order to ascertain the quantity of carbonic acid, the contents which had been dissolved were decomposed by muriate of lime: hence muriate of potash and carbonate of lime were obtained. This carbonate of lime was separated from the supernatant muriate of potash, and introduced into a glass globe, having a tube annexed to it. This globe and tube were then filled with mercury, and inverted in a vessel containing the same fluid. The lime by that means was made to occupy the very top of the tube. It now remained to separate the carbonic acid from the lime: it was therefore mixed with muriatic acid; by this means, 10.3 ounce measures of carbonic acid gas, or nearly 9.166 grains, were separated; but, according to the experiments of Lavoisier, this gas is composed of 72 parts of oxygen and 28 of carbon; 9.166 grains, therefore, contain 2.56 grains of carbon, which is almost the weight of the diamond consumed; and hence it follows, that it was composed of pure carbon, or the pure acidifiable basis of the carbonic acid.

The combustion of the diamond is effected at three different temperatures. At the first and least elevated temperature the diamond assumes a gray and black colour; this is the first degree of oxydation; it is the state of the plumbago and of the anthracolite, or incombustible pit-coal.

At the second degree of temperature there is a new, slow, and successive combination of oxygen; it then constitutes the habitual state of our charcoal.

Supposing, therefore, we could operate with sufficient precision to take from the surface of the diamond the black matter in proportion as it formed, during our experiment for burning it, we should undoubtedly convert the whole diamond into *charcoal.*

At the third degree of combustion the diamond is wholly converted into carbonic acid gas, as we have shown before.

Guyton Morveau has likewise converted soft iron into cast steel, by means of the diamond, in the following manner :* A cavity was bored in a block of soft iron, and a stopper fitted to it of the same metal. Into the cavity was put a diamond, with some filings of the block of iron, to fill the remaining space, after which the stopper was driven in. In this state the whole was put into a crucible, and this placed into another. The space between the two crucibles was filled with pure siliceous sand. The external crucible was well closed and luted, and the whole exposed to the strong ignition of a blast-furnace, by which the metal was fused completely ; the diamond disappeared, and the iron was thus converted into steel.

After all this, it will no doubt be demanded how it happens that the pure carbon or diamond is so scarce, whilst, when combined with oxygen, in the state of charcoal it is so abundantly dispersed through nature ?

We obtain by our chemical decompositions of bodies charcoal and not diamond. No chemist speaks of our exhaling diamond by respiration, but many of charcoal or at least carbonic acid.

To any disbelief of this matter it must be answered, that iron exists every where, under every form, except in the state of perfect purity, or uninsulated ; for the existence of pure native iron is still doubtful. The wonder consists, therefore, only in the difference between facts and our opinions ; it vanishes in proportion as we discover and appropriate the powers of nature to produce the same effects.

After these considerations of the facts now discovered regarding the diamond, the mind naturally turns itself to the possibility of forming diamonds by artificial processes. It cannot be said that this discovery, if made, would be of

* Annales de Chim. xxxi. p. 328.

any great advantage to mankind. It is difficult to conceive to what use this substance could be *generally* applied; and though the mention of a method of making diamonds might possibly procure a handsome fortune to the inventor, a publication of the process would infallibly lessen the value of diamonds so prodigiously, that the manufacture would considerably sink in value. If what has been advanced before be right, there is no want of materials from which diamonds might be made. All nature abounds with charcoal, or its combinations; whole mountains, nay kingdoms, are composed of chalk and limestone, in which diamonds ought to be contained in astonishing abundance. But, plentiful as this principle may be, there appears at present no likely method of obtaining it pure or uninsulated.

The diamond is advantageously used, on account of its excessive hardness, to engrave on hard stones and glass, or to cut them into convenient pieces. It is also used as an ornament. The extreme hardness, the labour of cutting and polishing it, together with its rarity, render it precious without the assistance of the caprice of fashion.

Before we proceed farther in the description of simple substances, it will be necessary to illustrate the nature and production of *gases*, together with their properties; for the agency of these bodies produces so considerable a number of the phenomena which distinguish some bodies from others, that without a previous acquaintance with them a great number of the experiments illustrative of the properties of simple substances would be unintelligible.

NATURE.

AND

FORMATION OF GASES.

(SEE APPENDIX, NO. 13.)

PART XIV.

SECT. I.

NATURE OF GASES.

BY the word *gases* we distinguish permanently elastic aeriform fluids, or substances which have the appearance of air; that is to say, they are transparent, elastic, ponderable, invisible,* and not condensible into a liquid or solid state by any degree of cold hitherto known.

Some of the gases exist in nature, without the aid of art, and may therefore be collected; others, on the contrary, are only producible by artificial means.

All gases are combinations of certain substances, reduced to the gaseous form by the addition of caloric and light. It is therefore necessary to distinguish in every gas the matter of heat which acted the part of a solvent, and the substance which forms the basis of the gas. Gases are not contained in those substances from which we obtain them in the state of gas, but owe their formation to the expansive property of caloric.

The bases of some gases are known to us, and may be exhibited in an uncombined state; others again are not producible by art.

* Oxygenated muriatic acid gas, and nitrous acid gas, are the only exceptions to this rule.

FORMATION OF GASES.

It has been mentioned before, that the different forms under which bodies appear depend upon a certain quantity of caloric chemically combined with them. The very formation of gases corroborates this truth. Their production totally depends upon the combination of particular substances with caloric; and those we call permanently elastic are only so because we cannot so far reduce their temperature as to dispose them to part with it; otherwise they would undoubtedly become fluid or solid.

Water, for instance, is a solid substance in all degrees below 32° of Fahrenheit's scale; above this temperature it combines with caloric and becomes a fluid. It retains its fluidity under the ordinary pressure of the atmosphere, till its temperature is augmented to 212°. It then combines with a larger portion of caloric, and is converted *apparently* into gas, or at least into elastic vapour; in which state it would continue if the temperature of our atmosphere was above 212°. Gases are therefore solid substances, between the particles of which a repulsion is established by the quantity of caloric.

But as in the gaseous water or steam the caloric is retained with but little force, on account of its quitting the water when the vapour is merely exposed to a lower temperature, we do not admit steam amongst the class of gases, or permanent aeriform elastic fluids. In gases, caloric is united by a very forcible affinity, and no diminution of temperature or pressure that has ever yet been effected can separate it from them. Thus the air of our atmosphere in the most intense cold still remains in the aeriform state; and hence is derived the essential characters of gases, namely, *that they shall remain aeriform, under all variations of pressure and temperatures.* (*See Appendix No.* 14.)

In the modern nomenclature, the name of every substance existing in the aeriform state is derived from its solid base; and the term gas is used to denote its existence in this state.

In order to illustrate the formation of gases, or to show in what manner caloric is combined with them, the following experiment may serve.

Experiment I.

Put into a retort, capable of holding half a pint of water, two ounces of muriate of soda (common salt) pour on it half its weight of sulphuric acid, and apply the heat of a lamp; a great quantity of gas is produced, which might be collected and retained over mercury. But to serve the purpose of this experiment, let it pass through a glass receiver, having two openings, into one of which the neck of the retort passes, whilst from the other a bent tube proceeds, which ends in a vessel of water. Before closing the apparatus, let a thermometer be included in the receiver, to show the temperature of the gas. It will be found that the mercury in the thermometer rises only a few degrees, whereas the water in the vessel which receives the bent tube will soon become boiling hot.

Rationale....Common salt consists of muriatic acid united to soda; on presenting sulphuric acid to it a decomposition takes place. The sulphuric acid unites by virtue of its greater affinity to the soda, and forms sulphate of soda, or Glauber's salt; the muriatic acid becomes therefore disengaged, and takes the gaseous form, in which it is capable of existing in our temperature. To trace the caloric during this experiment, as was our object, we must remark, that it first flows from the lamp to the disengaged muriatic acid, and converts it into gas; but the heat thus expended is chemically united, and therefore not appreciable by the thermometer. The caloric, however, is again evolved, when the muriatic acid gas is condensed by the water with which it forms liquid muriatic acid.

In this experiment we therefore trace caloric in a chemical combination producing gas; and from this union we again trace it in fire or sensible heat.

Such in general is the cause of the formation and fixation of gases. It may be further observed, that each of these fluids loses or suffers the disengagement of different quantities of heat, as it becomes more or less solid in its new combination, or as that combination is capable of retaining more or less specific heat.

PNEUMATIC APPARATUS.

The discovery of aeriform or gaseous fluids has occasioned the necessity of some peculiar instruments, by

means of which those substances may be conveniently collected and submitted to examination. The principal ones for that purpose are styled the *pneumatic apparatus.*

THE PNEUMATIC RESERVOIR OR CISTERN.

Is made either of wood or strong sheet-iron tinned, japanned, or painted. A trough of about two feet long, sixteen inches wide, and fifteen high, has been found to be sufficient for most experiments. Two or three inches below its brim, a horizontal shelf is fastened, in dimension about half or one-third part of the width of the trough. In this shelf are several holes: these holes must be made in the centre of a small excavation, shaped like a funnel, which is formed in the lower part of the shelf.

This trough is filled with water sufficient to cover the shelf to the height of an inch.

The use of this shelf is to support receivers, jars, or bell-glasses, which, being previously filled with water, are placed invertedly, their open end turned down upon the above-mentioned holes, through which the gases, conveyed there and directed by means of the funnel-shaped excavations, rise in the form of air-bubbles into the receiver.

When the gaseous fluids are capable of being absorbed by water, as is the case with some of them, the trough must be filled with mercury. The price and gravity of this fluid make it an object of convenience and economy, that the trough should be smaller than when water is used.

A mercurial trough is best cut in marble, free-stone, or a solid block of wood. A trough about 12 inches long, 3 inches wide, and four deep, is sufficient for all private experiments.

SECT. II.

METHOD OF COLLECTING GASES, AND TRANSFERRING THEM FROM ONE VESSEL TO ANOTHER.

PREVIOUS to undertaking experiments on gases, it may be well for the unexperienced operator to accustom

himself to the dexterous management of collecting and transferring common air.

Experiment I.

Methods of transmitting air from one vessel to another.

If we are desirous of transferring air from one vessel to another, it is necessary that the vessel destined to receive it be full of water, or some fluid heavier than air. For that purpose, take a wide mouthed bell-glass or receiver, plunge it under the water in the trough in order to fill it, then raise it with the mouth downwards, and place it on the shelf of the trough, so as to cover one or more of the holes in it.

It will now be full of water, and continue so as long as the mouth remains below the surface of the fluid in the cistern; for in this case the water is sustained in the vessel by the pressure of the atmosphere, in the same manner as the mercury is sustained in the barometer. It may without difficulty be imagined, that if common air (or any other fluid resembling common air in lightness and elasticity) be suffered to enter the inverted vessel filled with water, it will rise to the upper part on account of its levity, and the surface of the water will subside. To exemplify this, take a glass or any other vessel, in that state which is usually called *empty*, and plunge it into the water with its mouth downwards, scarce any of it will enter the glass, because its entrance is opposed by the elasticity of the included air; but if the vessel be turned with its mouth upwards, it immediately fills, and the air rises in bubbles to the surface. If this operation be performed under one of the jars or receivers which are filled with water, and placed upon the perforated shelf, the air will ascend in bubbles as before; but, instead of escaping, it will be caught in the upper part of the jar, and expel part of the water it contains.

In this manner we see that air may be emptied out of one vessel into another by a kind of inverted pouring; by which means it is made to ascend from the lower to the upper vessel. When the receiving vessel has a narrow neck, the air may be poured in a similar manner through an inverted funnel inserted in its mouth.

If the air is to be transferred from a vessel that is stopped like a bottle, the bottle must be unstopped with its orifice downwards in the water, and then inclined in such a manner that its neck may come under the perforated excavation of the shelf. The gas will escape from the bottle; and, passing into the vessel destined to receive it, will ascend in it in the form of bubbles.

In whatever manner this operation is performed, the necessity of the excavation in the lower part of the shelf may be readily conceived. It is, as mentioned before, destined to collect the gas which escapes from the vessel, and direct it in its passage towards the vessel adapted to receive it. Without this excavation, the gas, instead of proceeding to the place of its destination, would be dispersed and lost.

The vessels or receivers for collecting the disengaged gases should be glass cylinders, jars, or bell-glasses of various sizes; some of them should be open at both ends, others should be fitted with necks at the top, ground perfectly level, in order that they may be stopped by ground flat pieces of metal, glass, slate, &c. others should be furnished with ground stoppers; some should be graduated into cubic inches, and subdivided into decimal or other equi-distant parts. Besides these, common glass bottles, tumblers, &c. may be used.

CLASSIFICATION OF GASES.

All the elastic aeriform fluids with which we are hitherto acquainted are generally divided by systematic writers into two classes; namely, those that are *respirable* and *capable of maintaining combustion*, and those that are *not respirable* and *incapable of maintaining combustion*. This division indeed has its advantage; but the term respirable, in its physicological application, has been very differently employed by different writers. Sometimes by the respirability of a gas has been meant its power of supporting life, when repeatedly applied to the blood in the lungs. At other times all gases have been considered respirable which were capable of introduction into the lungs by voluntary efforts, without any relation to their vitality.

In the last case the word respirable seems to us most properly employed, and in this sense it will be used hereafter.

Non-respirable gases are those which, when applied to the external organs of respiration, stimulate the muscles of the epiglottis in such a manner, as to keep it perfectly close on the glottis; thus preventing the smallest particle of gas from entering into the bronchia, in spite of voluntary exertions.

Of respirable gases, or those which are capable of being taken into the lungs by voluntary efforts, according to their conditions, only one has the power of uniformly supporting life, namely, atmospheric air: other gases, when respired, sooner or later impair the health of the human constitution, or perhaps occasion death, but in different modes.

Some gases effect *no positive* change in the blood; animals immersed in it die of a disease produced by the privation of atmospheric air, analagous to that occasioned by their submersion in water.

Others again produce *some positive* change in the blood, as appears from the experiments of Dr. Beddoes and Professor Davy. They seem to render it incapable of supplying the nervous and muscular fibres with principles essential to sensibility and irritability. These gases, therefore destroy animal life on a different principle.

It is obvious, therefore, that the above classification does not hold good in all respects, but is capable of misleading the student. We shall not divide the gases we are going to treat of into different classes, for we do not see the advantage which can arise from any division; we shall therefore examine first those which are simple, the bases of which cannot be exhibited in an insulated state, namely, oxygen, nitrogen, and hydrogen gas. We shall then consider the combination of these gases with each other, in order to understand some of the most important phenomena in which they are concerned, together with the rest of those gases, of which the bases may be exhibited experimentally.

OXYGEN GAS.

PART XV.

SECT. I.

PROPERTIES OF OXYGEN GAS.*

OXYGEN gas is an elastic invisible fluid, like common air, capable of indefinite expansion and compression. It has neither taste nor odour, nor does it show any traces of an acid. Its specific gravity, as determined by Kirwan, is 0.00135, that of water being 1.0000; it is therefore 740 times lighter than the same bulk of water. Its weight is to atmospheric air as 1103 to 1000. 116 cubic inches of oxygen gas weigh 39.38 grains. It is not absorbed by water, but entirely absorbable by combustible bodies, which at the same time disengage its caloric and light, producing in consequence a strong heat and flame. It rekindles almost extinct combustible bodies; it is indispensable to respiration, and is the cause of animal heat; it hastens germination; it combines with every combustible body, with all the metals, and with the greater number of vegetable and animal substances; it is considered as the cause of acidity, and from this last property is derived the name *oxygen*, a word denoting the origin of acidity.

The act of its combining with bodies is called *oxydation* (oxydizement) or *oxygenation* (oxygenizement) and the bodies with which it is combined are called *oxyds*.

Oxygen gas is the chief basis of the pneumatic doctrine of chemistry.

* From ὀξυς acid, and γινομαι I am born.

METHODS OF OBTAINING OXYGEN GAS.

(*See Appendix No.* 15.)

We are at present acquainted with a great number of bodies from which we may, by art, produce oxygen gas. It is most amply obtained from the oxyds of manganese or mercury, from nitrate of potash, from the green leaves of vegetables, and from oxygenized muriate of potash, or soda. Besides these, there are a great many other substances from which oxygen gas may be procured.

Experiment I.

To obtain oxygen gas from oxygenized muriate of potash.

In order to procure oxygen gas in a state of great purity, pure oxygenized muriate of potash must be made use of. With this view, put some of the salt into a small earthen or glass retort, the neck of which is placed under the shelf of the pneumatic trough filled with water, and heat the retort by means of a lamp. The salt begins to melt, and oxygen gas will be obtained in abundance and of great purity, which may be collected and preserved over water.

Rationale...Oxygenized muriate of potash consists of oxygenized muriatic acid and potash: at an elevated temperature a decomposition of the oxygenized muriatic acid takes place: its oxygen unites to the caloric, and forms oxygen gas. The oxygenized acid becomes therefore converted into simple muriatic acid, which remains in the retort united to the potash, in the form of muriate of potash.

Experiment II.

To obtain oxygen gas from green leaves of vegetables.

Oxygen gas may likewise be obtained from the green leaves of vegetables.

For this purpose fill a bell glass with water, introduce fresh gathered green leaves into it, and place the bell or receiver inverted in a vessel containing the same fluid;

expose the apparatus to the rays of the sun, and very pure oxygen gas will be liberated.

The emission of oxygen gas is proportioned to the vigour of the plant and the vivacity of the light: the quantity differs in different plants, and under different conditions. (See page 157.)

RATIONALE....It is an established fact, that plants decompose water, and probably carbonic acid, which serve for their nourishment; they absorb the hydrogen and carbon of these fluids, disengaging part of the oxygen in a state of purity. Light, however, favours this decomposition greatly; it seems to serve for melting the oxygen, and thus forms it into oxygen gas: in proportion as it becomes disengaged, the hydrogen becomes fixed in the vegetable, and combines partly with the carbon and partly with the oxygen, to form the oil, &c of the vegetable.

EXPERIMENT III.

To obtain oxygen gas from nitrate of potash.

Nitrate of potash is another substance frequently made use of for obtaining oxygen gas, in the following manner: Take any quantity of this salt, introduce it into an earthen or coated glass retort, and fit to it a tube, which must be plunged into the pneumatic trough under the receiver filled with water. When the apparatus has been properly adjusted, heat the retort gradually till it becomes red hot, the oxygen gas will then be disengaged rapidly.

The gas obtained in this way is also very pure, especially if the last portion be kept separate.

RATIONALE....Nitrate of potash consists of nitric acid and potash. Nitric acid consists again of oxygen and nitrogen. On exposing the salt to ignition, a partial decomposition of the acid takes place; the greatest part of the oxygen of the nitric acid unites to caloric, and appears under the form of oxygen gas. The other part remains attached to the potash in the state of nitrous acid. The residue in the retort is therefore nitrite of potash, if the process has been carefully conducted.

REMARK....If too much heat be applied, particularly towards the end of the process, a total decomposition of

the nitric acid takes place; the oxygen gas in that case will therefore be mingled with nitrogen gas. The weight of the two gases when collected will be found to correspond very exactly with the weight of the acid which had been decomposed: the residue then left in the retort is potash.

Experiment IV.

To obtain oxygen from black oxyd of manganese.

Black oxyd of manganese, however, is generally made use of for obtaining oxygen gas, on account of its cheapness. This native oxyd is reduced to a coarse powder; a stone, or rather an iron retort, to which a conducting tube has been fitted, is then charged with it and heated. As soon as the retort becomes ignited, oxygen gas is obtained plentifully.

Rationale....Black oxyd of manganese is the metal called manganese fully saturated with oxygen, together with many earthy impurities: on applying heat, part of the solid oxygen quits the metal, and unites to caloric, in order to form oxygen gas; the remainder of the oxygen remains united to the metal with a forcible affinity; the metal therefore reapproaches to the metallic state, or is found in the state of a gray oxyd of manganese.

One pound of the best manganese yields upwards of 1400 cubic inches of oxygen gas, nearly pure. If sulphuric acid be previously added to the manganese, the gas is produced by a less heat and in a larger quantity; a glass retort may then be used, and the heat of a lamp is sufficient.

Red oxyd of mercury yields oxygen gas in a manner similar to that of manganese.

Rationale....This oxyd consists likewise of solid oxygen and mercury, the combination of which takes place on exposing mercury to a heat of about 610° Fahr. At this degree it attracts oxygen, and becomes converted into an oxyd; but if the temperature be increased to about 1000° the attraction of oxygen is changed. The oxygen then attracts the caloric stronger than it did the mercury; it therefore abandons it and forms oxygen gas. The mercury then reappears in its metallic state. (See p. 79.)

Red oxyd of lead yields oxygen gas on the same principle.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF OXYGEN GAS.

EXPERIMENT I.

Oxygen gas is not absorbed by water.

Let a cylindrical bell-glass be filled with oxygen gas, and agitate it in contact with water: the gas will not sensibly diminish in bulk, which is a proof that water does not absorb oxygen. It may, however, be made to combine with it, by means of artificial pressure.

DECOMPOSITION OF OXYGEN GAS, BY BODIES DESTITUTE OF METALLIC PROPERTIES.

EXPERIMENT II.*

Combustion of Phosphorus in oxygen gas.

Fill a bell-glass or receiver with oxygen gas, confine it by mercury, and introduce a piece of phosphorus through the quicksilver, which immediately will rise to the surface of it; then set fire to the phosphorus, by means of a crooked heated iron wire, introduced so as to touch it without disturbing the vessel. It will burn with a very brilliant flame. A considerable quantity of caloric and light will be liberated, and the whole inside of the glass will be covered with a white flaky crust, which will be found to be phosphoric acid; and the mercury will have ascended considerably.

RATIONALE....This experiment proves that a decomposition of the oxygen gas has taken place. The phosphorus at a certain degree of heat is capable of decomposing this gas; it attracts its ponderable base the oxygen, and becomes converted into phosphoric acid; the light and heat, which kept the oxygen in a gaseous state, together with those of the phosphorus, are then disengaged in the form of fire.

* This and the three following experiments show that oxygen is an acidifying substance.

If the phosphorus is weighed before the experiment, and the quantity of oxygen gas has been also ascertained, the weight of the produced acid will be found equal to the sum of the weights of the phosphorus consumed and oxygen absorbed, if the experiment has been conducted carefully. Forty grains of phosphorus absorb generally sixty-five of oxygen.

If the oxygen gas be pure, the residuum after combustion is as pure as the gas employed: this proves that nothing could escape from the phosphorus capable of altering the purity of the oxygen gas, and that the only action of the phosphorus is to separate the oxygen from the caloric with which it was before united.

This property of being convertible into an acid belongs to all combustible bodies: hence the combination of oxygen with such a body is called *oxygenation*, or oxygenizement.

Experiment III.

Combustion of sulphur in oxygen gas.

This experiment is best performed by filling a large receiver with oxygen gas in the water apparatus, and removing it by means of a flat dish into the mercurial trough, take care to leave a little water over the mercury. When this is done, put a small piece of sulphur into a copper ladle, set fire to it by means of a candle and blowpipe, and introduce it into the gas. The sulphur will burn with a beautiful blue flame: when the fumes have disappeared, the water over the mercury will be found to have an acid taste; it will turn blue vegetable colours red, and effervesce with carbonated alkalies. It is therefore an acid; and, as it is composed of sulphur and oxygen, it is called sulphuric acid. If the respective quantities of gas, sulphur, and water, have been previously ascertained, the water will be found to have increased in weight, as much as the sum of the weights of the sulphur and oxygen consumed.

Rationale....Sulphur is a simple combustible body, which possesses the property of decomposing oxygen gas at a high temperature, by attracting the oxygen from the caloric with which it was combined, in order to be converted into sulphuric acid.

Experiment IV.

Combustion of charcoal in oxygen gas.

The oxygenation of charcoal may be effected like that of phosphorus, in the receiver placed over mercury. But as the heat of the red hot iron is not sufficient to ignite the charcoal, a small piece of tinder, with a minute particle of phosphorus, are brought in contact with it; these being set on fire will kindle the charcoal, which then will burn, and throw out scintillating sparks in all directions.

After the combustion ceases, it will be found that the elastic fluid under the receiver has not disappeared, as was the case in the former experiments; but that a new peculiar kind of gas is formed. This air is unfit for respiration, and incapable of maintaining combustion. It is greatly absorbed by cold water, and vanishes by lime-water, barytic-water, or by other alkalies, which first are rendered turbid, and prove it to be an acid, consisting of charcoal and oxygen; hence it is called carbonic acid gas. Whatever quantity of gas remains after the absorption by alkalies is that portion of oxygen gas which has escaped the action of the charcoal during the combustion.

Rationale....The charcoal in this case likewise effects a decomposition of the oxygen gas. When charcoal is ignited, its affinity for oxygen is stronger than that of caloric; it therefore unites to it, and forms carbonic acid, which assumes the gaseous state at the temperature of our atmosphere. Part of the light and heat becomes liberated, and appears under the form of fire.

DECOMPOSITION OF OXYGEN GAS BY METALLIC SUBSTANCES.

Oxygen has likewise a great affinity for another kind of combustible bodies, we mean those called metals; particularly when heated to a certain degree. All metallic bodies, except gold, silver, and platina, have the property of decomposing oxygen gas, by attracting its ponderable base (the solid oxygen) from the caloric and light, which kept it in its gaseous state. They then lose their properties and approach to the acid state.

Experiment I.

Combustion of arsenic in oxygen gas, and production of arsenious acid.

Put into a copper ladle a piece of metallic arsenic, having previously affixed to it a small bit of wood or charcoal. Set fire to the charcoal by means of the blow-pipe, and quickly introduce it into the gas. The charcoal being inflamed, it will communicate the combustion to the arsenic, which will burn with a beautiful white flame. The receiver will become filled with dense white fumes, and a coat of arsenic will gradually cover the whole inside of the receiver. When the combustion has ceased, or when all the arsenic is burnt, let the receiver be moved out of the water-trough. A coat of white powder will be observed floating on the water, which is arsenious acid. This may be collected, and added to that adhering to the sides of the receiver.

Rationale.....Arsenic is a simple combustible body; on being presented under these circumstances to oxygen gas, it attracts the basis of it, with which it unites, and forms arsenious acid.

Experiment II.

Combustion of iron in oxygen gas.

This experiment may be exhibited in the most convenient manner as follows: a glass receiver, with a narrow open neck, must be provided. It may be closed at the top with a cork, or a rough-ground flat piece of glass or metal. It is to be filled with water and put upon the shelf of the pneumatic trough. Oxygen gas is then conveyed into it in the usual manner. When the receiver is filled with gas, a shallow basin or dish with water must be brought near it, so that the receiver may be removed with the gas, and easily slid into the basin. The gas is thus confined by the water, and the receiver may be removed to any convenient place. Iron wire of about $\frac{1}{30}$ of an inch in diameter must be coiled tightly round a stick of wood or glass, of about half an inch in diameter; the stick

is then withdrawn, and the wire will form a length of spiral rings. This wire, extended to about the inside length of the receiver, must be fixed in a cork, so that it may hang vertically, and may be readily introduced at the top of the receiver, and kept, by means of the cork, firm therein: at the other extremity of the wire, a little thread dipped in sulphur, or a piece of wood, is to be fixed. The thread or wood is then lighted, and the wire quickly introduced into the receiver; an intense deflagration of the wire immediately takes place, throwing out a number of brilliant sparks, ascending in a spiral direction, with a beautiful sun-like body, giving in a darkened room a luminous appearance inconceivably striking.

If we examine the weight of the iron after combustion, we find it augmented in proportion to the quantity of oxygen it has absorbed. It has at the same time lost its metallic splendour, and obtained properties different from those it possessed before.

The use of the heat employed for the first ignition is to separate the particles of the metal from each other, and to diminish the attraction of cohesion or aggregation.

RATIONALE....The iron, when heated to a certain degree, decomposes the oxygen gas: the equilibrium of the attraction subsisting between the caloric and solid oxygen being interrupted, it is acted upon by two separate and opposite forces, that of the attraction for caloric to remain in the gaseous state, and that exerted by the metal: the latter power being greater, it unites with it, and gives out at the same time its caloric and light. The new substance produced, consisting of oxygen and iron, is called *oxyd of iron.* It is not an acid, but it is changed to an intermediate substance, approaching to the acid state, though not possessing all the requisite properties.

EXPERIMENT III.

Combustion of zinc in oxygen gas.

Take some turnings of zinc, form a ball of them, and affix it to a copper wire; insert a small bit of phosphorus or charcoal into the ball, set fire to it, and introduce it quickly into a receiver filled with oxygen gas; the zinc will thus take fire, and burn with a beautiful green flame surrounded by a white one.

RATIONALE....This experiment is analogous to the former: the zinc unites to the oxygen of the gas at an elevated temperature, and the result is an oxyd of zinc.

EXPERIMENT IV.

If a current of oxygen gas be conveyed to filings or turnings of metals, they will burn with great rapidity.

For this purpose, fill a large bladder, or better fill the gazometer, with oxygen gas, and adapt to the bladder, or to the stop-cock of the gazometer, a tube; by pressing the bladder, or by pressing down the ball of the gazometer, and ejecting the gas on a piece of excavated ignited charcoal, into which filings of metal have been put, the metal will burn rapidly.

The filings which exhibit the most brilliant appearance are those of zinc, copper, antimony, iron, and steel.

DECOMPOSITION OF OXYGEN GAS BY VARIOUS OTHER SUBSTANCES.

EXPERIMENT I.

If a lighted wax taper fixed to an iron wire or ladle be let down into a vessel filled with oxygen gas, it will burn with great splendour. If the taper be blown out, and let down into the vessel of gas while the snuff remains red hot, it instantly rekindles with a slight explosion, and burns vividly.

EXPERIMENT II.

A piece of the bark of charcoal, fastened to a copper wire ignited, and then immersed in the gas, throws out brilliant sparks.

EXPERIMENT III.

A mixture of nitrate of strontia and charcoal powder, previously ignited, burns with a *rose coloured flame.*

EXPERIMENT IV.

A mixture of one part of boracic acid and three of charcoal burns *green.*

that of oxygen gas, water is formed;* with nitrogen it forms ammonia. It does not act on earthy substances: it is decomposable by a great variety of bodies.

METHODS OF OBTAINING HYDROGEN GAS.

It is not among natural products that hydrogen gas is to be collected. To obtain the purest hydrogen gas, or rather the least possible impure, consists in subjecting water to the action of a substance which is capable of decomposing this fluid.

1. For this purpose let concentrated sulphuric acid, previously diluted with six times its weight of water, be poured on iron filings or bits of zinc, in a small retort or gas bottle, called a pneumatic flask or proof: as soon as the diluted acid comes in contact with the metal, a violent effervescence takes place, and hydrogen gas escapes without external heat being applied. It may be collected in the usual manner over water, taking care to let a certain portion escape, on account of the atmospheric air contained in the disengaging vessel.

RATIONALE....The production of hydrogen gas is owing to the decomposition of water. The iron or zinc, when in contact with this fluid, in conjunction with sulphuric acid, has a greater affinity to oxygen than the hydrogen has; the oxygen therefore unites to it, and forms an oxyd of that metal, which is instantly attacked and dissolved by the acid; the other constituent part of the water, the hydrogen, is set free, which, by uniting with caloric, assumes the form of hydrogen gas, the oxygen is therefore the bond of union between the metal and the acid.

The hissing noise or effervescence observable during the process is owing to the rapid motion excited in the mixture, by means of the great number of air bubbles quickly disengaged, and breaking at the surface of the fluid.

REMARK....We see in this case that *two* substances exert an attraction, and are even capable of decomposing jointly a *third*, which neither of them is able to do singly, *viz.* if we present sulphuric acid alone, or iron or zinc

* Hence its name *Hydrogen*, which is derived from ὑδωρ, *water*, and γενομαι, *I am born.*

alone to water, they cannot detach the oxygen from the hydrogen of that fluid; but if both are applied, a decomposition is instantly effected. This experiment therefore proves, that the agency of chemical affinity between two or more bodies may lie dormant, until it is called into action by the interposition of another body, which frequently exerts no energy upon any of them in a separate state. (*See Chemical Affinity, law* V. *p.* 81.)

Instances of this kind were formerly called *predisposing affinities.*

2. Iron in a red heat has also the property of decomposing water, by dislodging the oxygen from its combination with hydrogen in the following manner.

Let a gun-barrel, having its touch hole screwed up, pass through the universal furnace, or through a large crucible perforated for that purpose, taking care to incline the barrel at the narrowest part; adjust to its upper extremity a retort charged with water, and let the other extremity terminate in a tube introduced under a receiver in the pneumatic trough. When the apparatus is thus disposed, and well luted, bring the gun-barrel to a red heat; and, when thoroughly red hot, make the water in the retort boil; the vapour, when passing through the red-hot tube, will yield hydrogen gas abundantly.

RATIONALE....In this experiment the oxygen of the water combines with the iron at a red heat, so as to convert it into an oxyd; and the caloric applied combines with the hydrogen of the water, and forms hydrogen gas. It is therefore the result of a double affinity, that of the oxygen of the water with the metal, and that of its hydrogen with caloric.

The more caloric is employed in the experiment of decomposing water by means of iron, &c. the sooner is the water decomposed.

* Hydrogen gas is frequently found in great abundance in mines and coal-pits, where it is sometimes generated suddenly, and becomes mixed with the atmospheric air of these subterraneous cavities. If a lighted candle be brought in, this mixture often explodes, and produces the most dreadful effects. It is called by miners *fire-damp.* It generally forms a cloud in the upper part of the mine, on account of its levity; but does not mix there with atmospheric air, unless some agitation takes place. The

* Rather carburetted hydrogen. T. C.

miners frequently set fire to it with a candle, lying at the same time flat on their faces, to escape the violence of the shock. An easier and more safe method of cleaning the mine is, by leading a long tube through the shaft of it, to the ash pit of a furnace: by this means the gas will be conducted to feed the fire.

Hydrogen gas, in whatever manner produced, *always* originates from water, either in consequence of a preceding decomposition, in which it had been combined, in the state of solid or fixed hydrogen, with one of the substances employed, or from a decomposition of water actually taking place during the experiment.

REMARKS....There are instances recorded of a vapour issuing from the stomach of dead persons, which took fire on the approach of a candle. We even find accounts in several works of the combustion of living human beings, which appears to be spontaneous. Dr. Swediaur related some instances of porters at Warsaw, who, having drank abundantly of spirit, fell down in the street with the smoke issuing out of their mouths; and people came to their assistance, saying they would take fire; to prevent which they made them drink a great quantity of milk, or used a more singular expedient, by causing them to swallow the urine of the bystanders, immediately on its evacuation.

However difficult it may be to give credit to such narratives, it is equally difficult to reject them entirely, without refusing to admit the numerous testimonies of men who were for the most part worthy of credit. *Citizen Lair* has collected all the circumstances of this nature which he found dispersed in different books, and has rejected those which did not appear to be supported by respectable testimony, to which he has added some others related by persons still living. These narratives are nine in number; they were communicated to the Philomatic Society at Paris, and inserted in the bulletin, Thermidor, An. 5, No. 29.

The cause of this singular phenomenon has been attributed to a developement of hydrogen gas taking place in the stomachs of these individuals.

Citizen Lair believes that the bodies of these people were not burned perfectly spontaneously; but it appeared to be owing to some very slight external cause, such as the fire of a candle, taper, or pipe.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF HYDROGEN GAS.

EXPERIMENT I.

Hydrogen gas is considerably lighter than atmospheric air.

Fill a receiver or wide-mouthed bottle with hydrogen gas, and let it stand for a few minutes, with its open mouth upwards, exposed to the air. On letting down a lighted candle into the bottle, the gas will be found to have escaped, for the candle will burn with its usual splendour.

If another jar, filled with the gas, be placed with its mouth downwards, the air will be prevented from ascending by the bottom and sides of the vessel, as may be proved by inserting a lighted candle, which will be instantly extinguished.

EXPERIMENT II.

Soap bubbles filled with hydrogen gas ascend rapidly.

Fill with hydrogen gas a bladder, and adapt to it a common tobacco pipe; dip the bowl of the pipe into a lather of soap, squeeze it gently in order to form a bubble, and detach it in the usual manner. These bubbles will rise rapidly into the air; if a lighted taper be presented to them, they catch fire and burn without noise.

If into a basin of soap-suds a mixture of hydrogen gas and atmospheric air be blown, by means of a bladder and pipe, so as to form bubbles over a considerable part of the surface of the suds, and a lighted match be then presented to it, the whole will explode with a loud report.

The theory of balloons or aerostatic machines is founded on the levity of hydrogen gas. It is sufficient that the weight of the balloon itself, and of the enclosed gas, should be lighter than an equal bulk of common air; and it must rise till its weight is in an equilibrium with an equal volume of the surrounding medium. The theory of the *Mongolfiers* is very different from this.

Experiment III.

Hydrogen gas extinguishes burning bodies.

Bring an inverted jar, filled with hydrogen gas, over the flame of a candle, and depress the jar at once, so that the lighted wick may be wholly surrounded by the gas. The candle will immediately be extinguished.

Experiment IV.

Hydrogen gas is unfit for combustion.

Introduce hydrogen gas into a jar filled with mercury; when the mercury is displaced, pass up into the gas a piece of tinder, to which is affixed a little phosphorus, and apply to the latter a heated wire. As soon as the phosphorus is touched with the hot wire it will melt, but will not burn; the gas is therefore unfit for combustion.

Experiment V.

Hydrogen gas is unfit for respiration.

Take a bell-glass, ground at the top; having filled it with hydrogen gas, put a bird, or any other animal, into it, and cover it with a ground-flat piece of glass, to prevent the fluid from escaping. The animal confined in the gas will be thrown into violent convulsions and soon expire, but merely on account of atmospheric air being excluded, for the hydrogen gas has suffered no alteration. (*See Appendix No.* 18.)

Experiment VI.

Hydrogen gas is only inflammable in contact with atmospheric air, or oxygen gas.

Fill a narrow-mouthed phial with hydrogen gas, and take it from the pneumatic trough by placing the thumb on the mouth thereof to prevent the gas from escaping. If a lighted taper be applied to the mouth of the bottle, the gas will take fire and burn with a lambent flame. The gas will only burn in contact with the atmospheric air;

the flame will descend gradually till all the gas is consumed; but if the taper be immersed in it, it becomes extinguished, as we have seen before, Experiment III.

If the hydrogen gas be pure, the flame is of a blue colour; but if the gas holds any substance in solution which is generally the case, the flame is tinged of different colours according to the substance. It is most usually reddish, because the gas holds in solution a little charcoal.

Experiment VII.

The philosophical candle which cannot easily be blown out.

Fill with hydrogen gas a bell-glass, furnished with a capillary tube; compress the gas, by making the bell descend below the level of the water in the pneumatic trough, then apply a lighted taper to the upper extremity of the tube, the gas will take fire, and exhibit a candle which will burn till all the gas is consumed.

Artificial fire-works may be constructed by filling bladders with hydrogen gas, and connecting them with revolving jets, tubes, &c. bent into different directions, and formed into various figures, which are pierced with holes of different sizes. The air being forced through these holes by pressing the bladders will, when inflamed, exhibit a curious fire-work without noise or smoke.

It is on similar principles that Mr. Cartwright's fire-works were formed.

By the combination of the inflammable property of hydrogen gas and the effects of electricity a curious philosophical lamp has been invented by *Volta*, which, by the turning of a stop-cock only, may instantly be lighted many hundred times: for a particular description of which we refer our readers to Adams's Lectures on Natural Philosophy, vol. ii. p. 98.

All these experiments show that hydrogen gas, which is not inflammable when alone, possesses that property when in contact with atmospheric air.

Hydrogen gas burns in proportion as it is environed with a larger quantity of atmospheric air or oxygen gas. As hydrogen gas and oxygen, or atmospheric air, have a like aggregation, it is possible to mix them in such a manner, as that every particle of each gas shall be contiguous

to a particle of the other, in which case they will burn with great rapidity.

Experiment VIII.

Detonation of hydrogen and atmospheric air.

Fill a strong bottle, capable of holding about four ounces of water, in such a manner that there may be one part of hydrogen gas and two of atmospheric air. On applying a lighted taper the mixture will not burn silently, but the whole will explode with a loud report, and the inside of the bottle will become moist.

Remark....It is prudent to wrap a handkerchief round the bottle, to prevent it from doing any injury if it should burst. The safest way of making this experiment is with a bottle of elastic gum.

The same experiment may be repeated with oxygen gas instead of atmospheric air, changing the proportions, and mixing only one part of oxygen gas with two of hydrogen. The explosion will then be much louder than in the foregoing experiment.

Experiment IX.

Hydrogen gas is absorbed by charcoal.

Charcoal has the property of absorbing hydrogen gas, but it takes up a smaller portion than any other gas hitherto tried. If a tall cylinder, or eudiometrical tube, be filled with hydrogen gas, and a piece of fresh prepared charcoal be passed up into it, the volume of the gas will speedily become diminished.

Remark.....Morozzo found that a piece of charcoal, 12 lines long and 8 in diameter, extinguished in mercury; and when plunged into a tube, 144 lines long and 12 in diameter, and filled with this gas, absorbed $\frac{1}{5\frac{1}{2}}$ of the whole. Messrs. Rouppe and Van Noorden noticed, that new-made charcoal, allowed to cool without being exposed to the air, when plunged into hydrogen gas, absorbed about half its bulk of it. When charcoal thus impregnated with hydrogen gas is exposed to common air, the oxygen of the air combines with the hydrogen, and forms

water. The same phenomenon takes place when oxygen gas is employed instead of common air.*

Experiment X.

To charge and fire a cannon or pistol by means of hydrogen gas.

This experiment may be made advantageously by means of an apparatus, sold under the name of the inflammable air pistol or cannon.

To charge this pistol nothing more is necessary but to introduce its open end into a wide mouthed bottle, filled with a mixture of oxygen and hydrogen gas, leaving it in for a few seconds; it is then to be stopped with a cork, and may be fired by the electric spark, taken either from the prime conductor of the machine or a charged Leyden vial.

Experiment XI.

The production of water by detonating hydrogen and oxygen gases

Is founded on the same principle. Take a strong glass tube, about half an inch in diameter and twelve inches long, closed at one end, and graduated into cubic inches, or any other equi-distant parts. About half an inch from the closed end or top, two small holes are drilled opposite to each other, and into each of these a wire or conductor is to be cemented, so that the two points may be distant from each other, within the tube, about one-eighth of an inch or less. Into this tube, standing in water, two parts in bulk of hydrogen gas, and five parts of atmospheric air, are transferred. The tube is then to be firmly held, and an electric spark is passed, by means of the conductors, through the mixture of the gases; an immediate explosion takes place, the volume of the gases will be diminished, and the water will ascend in the tube; for the whole of the hydrogen gas is consumed, and likewise all that part of the common air which consisted of oxygen gas; and there is formed a quantity of water equal in weight to these two bodies.

* Ann. de Chim. xxxii. 18.

RATIONALE....The hydrogen gas robs the atmopheric air of the whole portion of oxygen gas it contained; this mixture being fired by the electric spark disappears, and forms water. The residue therefore indicates the quantity of nitrogen gas which was contained in the given bulk of atmospheric air with considerable accuracy.

REMARK....If mixed in the proportion of one part in bulk of the former, and two parts of the latter gas, or more accurately, 85 parts by weight of oxygen gas, and 15 of hydrogen gas, and then exploded over water, the volume of the gases disappears: and the exploding tube in which they were contained becomes completely filled with water, on account of the total vacuum which had been formed.

If the explosion be made in a close vessel, or over mercury, a quantity of water is always produced, equal in weight to the gases employed.

This water must be composed of the two gases; for it did not previously exist in the vessel, and no other substance besides the gases was introduced. Water then is composed of oxygen and hydrogen; and the combustion of hydrogen is nothing but the act of its combination with oxygen.

It has been with great plausibility conjectured, that detonations in the air, or claps of thunder, are similar effects of the combustion of hydrogen and oxygen gas; and that the rain which falls so copiously at the time of thunder storms is owing to a sudden formation of water in the atmosphere, from the rapid combustion of the hydrogen and oxygen gases fired by an electric spark.

The diminution of hydrogen and oxygen gases by their bases may also be shown in the following manner:

EXPERIMENT XII.

Fill a tall jar with oxygen gas, and fill also with hydrogen gas a bladder, furnished with a stop cock, and with a long brass pipe like the letter S, and drawn out to a fine point. On pressing the bladder a stream of gas will issue from the pipe, which may be set fire to, and brought cautiously under the inverted jar of oxygen gas. By this intercourse the stream of hydrogen gas will be burnt in a con-

fixed portion of oxygen gas: by continuing the combustion a sufficient time, the water will rise gradually within the jar. On the first impression of the heat indeed a small quantity of gas will escape from the jar, which will render it difficult to ascertain what degree of absorption actually takes place. But this loss may be prevented by using a jar, with a neck at the top, to which a compressed bladder is firmly tied. The expanded air, instead of escaping through the water, will now enter the bladder at the top; and when the experiment is closed and the vessels have cooled, it may be ascertained, by pressing out the gas from the bladder, what quantity of oxygen gas has been consumed. When this experiment is made with the substitution of common air for oxygen gas, a diminution takes place, but much less considerable, *viz.* not amounting to one-sixth of the original bulk of the gases.

RATIONALE....The disappearance of the gases depends on the union of their bases, which takes place during the state of ignition, and forms water, as has been noticed already.

Though hydrogen gas unites with oxygen gas only by the effect of combustion, exerted by the contact of an inflamed body, yet the hydrogen contained in a great number of combinations, even solid, combines probably in various ways hitherto unknown to us, and produces different with different bodies.

It has been mentioned before that hydrogen gas kills animals when immersed in it; but this gas is not itself destructive to animal life. Scheele first inspired it several times successively without danger, and almost without uneasiness. Other chemists and philosophers have since repeated this experiment with success.

Pilatre de Rozier breathed hydrogen gas six or seven times from a bladder without inconvenience. (*See Appendix No.* 19.)

NITROGEN GAS.

PART XVII.

SECT. I.

PROPERTIES OF NITROGEN GAS.

NITROGEN gas, or azotic gas, as it is also called, is not possessed of any remarkable property capable of characterizing it; but is principally distinguished by certain negative qualities, namely: it is extremely hurtful to respiration, and quickly kills animals;* plants thrive and even flourish in it; it has no sensible taste; it neither reddens blue vegetable colours, nor precipitates lime or barytic water; its weight is to common air as .985 to 1.000. No combustible substance burns in nitrogen gas; but it is capable of combustion in combination with oxygen gas when exposed to the action of the electric spark: it is not absorbable by water; it is capable of dissolving sulphur, phosphorus, and charcoal, in minute quantities; it unites to hydrogen under certain conditions, and constitutes with it ammonia. When united to oxygen in different proportions it produces atmospheric air, gaseous oxyd of azote or nitrogen, nitrous gas, nitrous acid, and nitric acid; it is a component part of all animal substances, and communicates to them their most distinctive characters: it was discovered by Dr. Rutherford of Edinburgh in 1772.

* Hence the name azote, which signifies "destructive to life," from α and ζωη.

Nitrogen gas has been found by Priestly in the Bath waters, and by Pearson in the Buxton waters.

METHODS OF OBTAINING NITROGEN GAS.

Nitrogen gas may be obtained by various means: for instance, it has been long since ascertained that air, which has served the purposes of combustion and respiration, is no longer proper for these uses. Chemists have availed themselves of this circumstance, in order to obtain nitrogen gas in the following manner.

1. Make a quantity of sulphuret of potash or sulphuret of iron into a paste with water, and place the mixture in a saucer or plate over water, on a stand raised above the fluid; then invert over it a jar or bell-glass, and allow this to stand for a day or two. The air contained in the bell-glass will gradually diminish, as will appear from the ascent of the water, until only about three fourths of its original bulk remain.

When no further diminution takes place, the vessel containing the sulphuret must be removed, and the remaining air will be found to be nitrogen gas.

RATIONALE....The moistened sulphuret of potash has a great affinity to oxygen; it attracts and separates it from the atmospheric air, and the nitrogen gas is left behind; the sulphur is during the experiment converted into sulphuric acid, which unites to the alkali, and forms sulphate of potash. The water with which the sulphuret is moistened likewise undergoes a decomposition, as shall be more fully proved in another place.

2. Nitrogen gas may likewise be obtained from fresh animal substances. For this purpose cut a piece of lean muscular flesh into small pieces, introduce them into a retort, and pour over them nitric acid of commerce, diluted with treble its bulk of water. If the heat of a lamp be then gently applied the gas will be speedily obtained.

RATIONALE....Animal substances are composed of nitrogen, carbon, hydrogen, and oxygen. On adding nitric acid the equilibrium of the respective affinities is destroyed, the nitrogen gas becoming separated.

That the nitric acid does not furnish the nitrogen gas is obvious, from its saturating after its action as large a

quantity of alkali as before; consequently it could not have suffered any alteration.

REMARK....The fibrous part of animal matter is that which affords the most nitrogen gas; next to this, all the concretive parts, such as the clot of blood; next to that, albuminous matter, such as the serum and white of eggs, cheese: gelatinous substances afford the least.

3. Nitrogen gas may likewise be obtained by causing oxygenated muriatic acid gas to be received in a vessel containing liquid ammonia.

RATIONALE....Ammonia consists of hydrogen and nitrogen. The hydrogen of the ammonia unites to the oxygen of the oxygenated muriatic acid, and forms water; heat is evolved, the nitrogen becomes free, and the oxygenated muriatic acid becomes converted into simple muriatic acid.

Other methods of obtaining nitrogen gas will be given in the next part.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF NITROGEN GAS.

EXPERIMENT I.

*Nitrogen gas is not absorbable by water.**

Take a long glass tube, divided into equal measures, which are distinguished by marks made with a diamond or file; send up into it any quantity of nitrogen gas; on agitating it strongly over water no absorption will take place, the volume of the air will not be sensibly diminished. (*See Appendix No.* 20.)

EXPERIMENT II.

Nitrogen gas does not exhibit signs of acidity.

Fill a receiver with pure nitrogen gas, and introduce therein a piece of litmus paper, or a small quantity of

* It is. See Appendix No. 20.

tincture of red cabbage, no change of colour will be produced in either of them; the gas therefore cannot be acid.

Experiment III.

Nitrogen gas does not maintain combustion, and is fatal to animal life.

This may be proved by plunging a lighted taper into a glass filled with this gas; the taper will be immediately extinguished.

If a small animal, such as a mouse or bird, be immersed in the gas, it instantly dies.

Experiment IV.

Nitrogen gas is capable of combustion with oxygen, at a high temperature.

Take a barometer tube, the diameter of which is about the sixth part of an inch. Shut one of its ends with a cork, through the middle of which passes a small wire, with a ball of metal at each end. Fill the tube with mercury, and invert it into a basin of this fluid. Throw up into the tube as much of a mixture of 13 parts of nitrogen gas and 87 parts of oxygen gas as will fill three inches. Through this gas, by means of the wire in the cork, pass a number of electric sparks; the volume of the gas gradually diminishes, and in its place will be found nitric acid.

Experiment V.

A mixture of nitrogen gas and oxygen gas produces artificial atmospheric air.

Introduce into a bell glass filled with water four parts of nitrogen gas and one of oxygen gas: after shaking the mixture well together, an air will be formed greatly resembling that of our atmosphere; for if a lighted taper, or any other burning substance, be plunged into this fluid, it will burn in the same manner as it does in atmospheric air; it may be breathed with safety, and animals confined in it will live as long as in an equal quantity of atmospheric air.

REMARK....Though we are not capable of producing in this manner an air absolutely the same as that of the atmosphere, the fault is not to be attributed to our ignorance of the quantity and quality of the gaseous bases, but to a difference in their union: in the atmosphere the union of the two gases is a true chemical combination, but in our experiments the mass of the formed air is a mere mechanical mixture.

EXPERIMENT VI.

Nitrogen gas does not precipitate lime from lime water.

This may be proved by putting a quantity of lime water into a tube filled with the gas, and shaking it. The transparency of the lime water will not be injured. (*See Appendix No.* 21.)

ATMOSPHERIC AIR.

PART XVIII.

THE whole globe of the earth is surrounded by, or is involved in, a fluid, called *air*, which though not perceived by our eyes is however manifested in various ways.

Whatever has been hitherto stated relative to the different kinds of aeriform fluids is chiefly important, because the knowledge of them is necessary to enable us to comprehend the nature of the air or gaseous fluid in which we are plunged the moment we are born, and in which we exist. This fluid which surrounds the earth to a considerable but unknown height above its surface, is called

THE ATMOSPHERE.

As fishes are surrounded by water, and live and move in water, so are we human beings, and all other animals, surrounded by air, and live and move in air. A fish which is taken out of the water will die in a short time; and a human being, or any animal, taken out of the aerial fluid, will in general die much sooner. Water gravitates towards the centre of the earth, and so does air. Hence as a fish or any body in water is pressed on every side by that fluid, so are other animals, &c. pressed on every side by the surface of air, and this pressure (as will be shown hereafter) is very considerable.

As the progressive motion of water from one place towards another is called a *current* of water, so the progressive motion of the air is called in general *wind*, which according to the different velocities of that fluid is more particularly specified by the appellation of *breeze*, *gentle wind*, *gale*, &c.

In treating of the different aeriform fluids which have hitherto been the subject of our consideration, it was necessary in some measure to anticipate the present, and to intimate that the air of our atmosphere is not, as was formerly supposed, a simple or homogeneous fluid, but that in reality it is composed of two distinct fluids, called oxygen gas and nitrogen gas.

Strictly speaking, the air of our atmosphere is however not so simple a substance as to be formed only of two ingredients. Besides the two bodies of which it is composed, it contains a small portion of another gaseous fluid, called *carbonic acid.*

It is also well known that a large portion of water is generally contained in the atmosphere, besides a great variety of substances which are subject to evaporation, and which are capable of existing in an aeriform state at the usual temperature.

SECT. I.

MECHANICAL EXAMINATION OF ATMOSPHERIC AIR.

By mechanical examination we would be understood to mean such properties as are connected with sensible changes of motion, and which indicate the presence and agency of moving or mechanical powers. They are therefore strictly the subject of mathematical discussion; admitting of measure, number, and direction; notions indeed purely mathematical. But as those mechanical properties characterize, or are peculiar *to all kinds* of elastic aeriform or gaseous fluids, no objection occurs to us against the propriety of considering them here briefly.

The mechanical properties of atmospheric air are GRAVITY, ELASTICITY, INDIVISIBILITY, and DILATABILITY.

GRAVITY OF ATMOSPHERIC AIR.

EXPERIMENT I.

To prove the weight of the air, a pair of common bellows may serve; thus, for instance, if we stop the

nozzle and secure the valve hole closely, having first blown or squeezed all the air out of them, we shall find that a considerable force is requisite for separating the boards. They are kept together by the pressure of the air, which surrounds them, in the same manner as if they were immersed in water.

Experiment II.

In like manner, if we stop the end of a syringe, after its piston has been pressed down quite to the bottom, and then endeavour to draw it up, we shall find a considerable force necessary, *viz.* about 15 pounds for every square inch of the section of the syringe. Exerting this force, we can draw up the piston and hold it there; but the moment we cease pulling, the piston rushes down again. We feel something as it were drawing in the piston, but it is solely the weight of the incumbent air pressing it: and this obtains in every position of the syringe: because the air is a fluid, and presses in every direction; nay, it presses on the syringe as well as on the piston; for if the piston be suspended by its ring on a nail, it will require a weight to draw down the syringe equal to that which is necessary to draw up the piston, and as soon as the syringe is freed from the weight it will spring up to its place again.

That the air presses equally in all directions becomes obvious from the following experiments.

Experiment III.

In a tall phial let an orifice be made about three inches from the bottom: stop this orifice. Through a cork in the neck of the phial, insert a long tube open at each end, and let the lower end be below the orifice in the side of the phial. The mouth of the phial being closed up about the tube, pour water into the tube till it is full. Upon opening the orifice, the water will be discharged, till its surface in the tube is level with the orifice; after which it will cease to flow, because the external lateral pressure of the air balances the perpendicular pressure upon the water in the tube.

Experiment IV.

If a conical wine glass be entirely filled with water, and covered with a flat piece of paper; on inverting the glass, the water will be kept from falling by the upward pressure of the air.

Experiment V.

If a vessel be perforated with small holes at the bottom but closed at the top, the upward pressure of the air will keep water within the vessel, as will appear by successively stopping and unstopping a small hole in the top.

The pressure of the air may be shown by means of the air pump.

Experiment VI.

Let the air be exhausted from a glass receiver placed on the pump, the vessel will be held fast by the pressure of the external air.

Experiment VII.

Let a small receiver be placed under a large one, and both be exhausted; the larger will be held fast, while the small one, being protected from the pressure of the air, may be easily moved.

Experiment VIII.

If the hand be placed upon a small open vessel, in such a manner as to close its upper orifice, it will be held down with great force, if the vessel be exhausted.

Experiment IX.

If the mouth of an open receiver be closely covered with a piece of bladder, and then exhausted, the superincumbent air will burst the bladder with a loud report. In a similar situation, a thin plate of glass may be broken.

Experiment X.

If a glass bulb with a long neck filled with water be put inverted into a vessel of the same fluid, placed under a receiver, and the latter be exhausted, on re-admitting the air, its pressure upon the surface of the water in the vessel will cause the fluid to rise up in the bulb.

Experiment XI.

If on a plate, called a *transferrer*, the air be exhausted from a long receiver, and then water be admitted through a pipe by means of a stop-cock, the water will be pressed up, and form a fountain.

Experiment XII.

If the air be exhausted from a vessel, and by means of a cock kept so, and the vessel be weighed while it is empty, and again weighed when the air is re-admitted; the difference will be the weight of the quantity of air the vessel contains.

Experiment XIII.

Fill a glass tube, about three feet long, and closed at one end, with mercury; then insert the open end in a cup or vessel of the same fluid. The mercury in the tube will be kept suspended, by the pressure of the external air on the surface of that which is on the open cup: when this pressure is removed by placing them under a receiver, and exhausting it, the mercury in the tube will sink, and rise again on re-admitting the air.

On the gravity of the air depends the ascent of water in pumps, syphons, &c. and the phenomena of the barometer.

The weight of the air compresses all fluids, and resists their dilatation; it opposes the evaporation of fluids, &c.

The gravity of the air resists the dilatation of the animal fluids; for the blood often bursts through the skin, or from the lungs, on the top of high mountains, occasioning hemorrhages, &c. because the air is there considerably lighter than near the level of the sea.

By the pressure of the air, the sucking of animals, the art of cupping, and many other phenomena, are explained, too numerous to be noticed here.

The operation of sucking in *general* consists in removing the pressure of the atmosphere from a certain part of the surface, whilst that pressure is at liberty to act on some other part of the surface; in consequence of which, the fluid is forced to ascend where the pressure has been removed or diminished.

If a man apply his mouth to the aperture of a bottle full of liquor, and holding his head straight up, he will not be able to suck any liquor out of it; but if a hole be opened at the bottom of the bottle, then the liquor may be sucked out of it. And the same effect will take place if an open tube be set with one end in water, and a man apply his mouth to the other end, and suck. The mechanical part of the operation is as follows: by enlarging his chest, the man rarefies the air, and of course diminishes its pressure on the liquor which is immediately under the tube; in consequence of which, the pressure of the atmosphere on the surface of the surrounding liquor forces it to ascend into the tube.

Thus the doctrine of the gravity and pressure of the air being established, by the most unexceptionable evidence, we are entitled to assume, *a priori*, all its legitimate consequences.

SPECIFIC WEIGHT OF ATMOSPHERIC AIR.

A bulk of atmospheric air that is equal to an English quart, when taken near the level of the sea, and at about 50° Fahr. weighs at a medium about 16 grains,* and the same bulk of rain-water at the same temperature weighs about 14621 grains. Hence rain-water is about 914 times specifically heavier than air.

The pressure of the air is equal to about 15 pounds troy on every square inch, and this pressure is the same in every direction. A square mile contains 27,878,400 square feet. The earth's surface in round numbers is 200,000,000 square miles, and therefore the pressure of the atmosphere circumfused about the whole surface of the earth is 12‴,043,468″,800,000′,000,000 pounds.

The surface of a middle-sized man is about 14 square feet; he sustains therefore a weight of air that is equal at a medium to about 30,240 pounds troy, or 24,882½ pounds avoirdupois nearly, or 1777 stone and 4 pounds, or 11 tons, 2 cwt. 18½ lbs.

Though our body supports such an enormous weight, we need not wonder at the freedom with which we traverse this atmosphere. We see fish move with as great

* 100 cubic inches, the thermometer of Fah. being at 60 degrees and the barometer at 30 inches, weighs 30,78 grains.

ease in a much more dense and more ponderous fluid. We are not sensible of the weight of the air, on account of its being equally applied on every side, besides, that we have been accustomed to support it from our earliest infancy. Sensations to which we have at all times been habituated are not felt; we can perceive no difference where we have no standard to judge of variations.

ELASTICITY OF ATMOSPHERIC AIR.

That the air is an elastic fluid, or capable of compression and expansion, may be proved by a great number of experiments. In fact the elasticity or spring of the air produces the same effect as the pressure, because the pressure is equal to the compressing force; for if it were less, it is clear it would yield and be more compressed; were it greater, it would not be so much reduced; for action and re-action are always equal.

The air gun, the effects of which are generally known, illustrates the elasticity of the air, and shows the compression it is susceptible of.

A foot ball or bladder filled with air rebounds from any hard body.

The elasticity of the air is also proved by fish and other animals. The former have received from nature various means of action; among these is an air bladder, which they contract or dilate at pleasure, and by this double property they ascend or descend in the water.

INVISIBILITY OF AIR.

The invisibility of air suggests the vulgar idea of its being nothing: but it must be considered that transparent bodies, such as let the rays of light pass freely through them, cannot be seen. Thus water, glass, air, &c. cannot be perceived by an eye, which is entirely surrounded by any of them. And even when that is not the case, we can only perceive those substances by the heterogeneous bodies which they may happen to contain, or by the refraction, inflection, &c. of the rays of light at their surfaces; hence, when such bodies are absolutely pure, and their surfaces are removed from our sight, so that we cannot observe the bending of the rays of light at those surfaces, then it is impossible to discern the bodies themselves.

If a glass bottle entirely filled with perfectly transparent water be situated against a dark place, so that no objects may be seen through it, a person who looks directly at it will not be able to say whether the bottle be full of water or not. A fish, or man in water, will feel the water, but cannot see it. The particles which are seen moving about when light passes through a hole in a room otherwise dark, are not the particles of air, but they are particles of dust, &c. which float in the air. Hence,

Atmospheric air when confined in vessels is absolutely invisible, and cannot be distinguished from the glass which contains it. It owes this property, as stated before, to the ready passage it affords to the rays of light, which are refracted without being reflected, and it is therefore destitute of colour; though some philosophers have persuaded themselves that they discovered large masses of it to be of a blue colour, as is the case in the sky, or in viewing extensive landscapes. But this is certainly a mistake; the blue colour is occasioned by the vapours which are always mixed with the air, and which have the property of reflecting the blue rays more copiously than any other.

It appears, from the very accurate observations of Saussure, that the colour of the sky acquires a deeper shade in proportion as it is viewed from a more elevated situation.* Consequently at a certain height the blue will disappear altogether, and the sky appear *black*, that is to say it will reflect no light at all.

DILATABILITY OF AIR.

We have noticed already (page 98) that if a flaccid or half blown bladder be exposed to the action of caloric, the air will be dilated so as to burst the bladder.

Experiment I.

To the bottom of a hollow glass ball let an open bended tube be affixed. Let the lower part of the bended tube be filled with mercury: the external surface will be pressed by the weight of the atmosphere, and the air en-

* Journal de Physique, March 1777, and Saussure's Voyages dans les Alpes.

Saussure's Cyanometer, was a board painted with all the shades of blue from a light blue to the deepest, approaching to black.

closed in the ball of the tube by means of the mercury will be equally pressed by the spring of the air within the vessel. If the ball be immersed in boiling water, the increased elasticity of the included air will raise the mercury in the tube.

REMARK....The theory of the Mongolfiers depends on the rarefaction of the air. In this case a given volume of atmospheric air is rarefied by heat, and kept separated from the common mass by a hollow vessel of cloth. This rarefied space may therefore be considered as consisting of a mass of air of greater levity than atmospheric air. It must therefore make an effort to rise in it.

SECT. II.

CHEMICAL EXAMINATION OF ATMOSPHERIC AIR.

CHEMISTRY affords two general methods of investigating the constituent parts of bodies, Analysis and Synthesis; that both of these methods can be applied in the investigation of the nature of atmospheric air we shall endeavour to prove.

From some ingenious experiments Lavoisier has demonstrated, as stated already, that the air of our atmosphere is not a simple homogeneous fluid, but consists of two elastic aeriform bodies, possessing very different properties; (*See Appendix No.* 22.) one of which is capable of supporting combustion and animal life, called oxygen gas, and the other is destructive to animals and extinguishes fire, called nitrogen gas. The atmosphere contains some other gaseous fluids, or bodies capable of being dissolved or suspended in it, but in small quantities. Late experiments seem to have proved that a minute quantity of carbonic acid is always contained in the air, for alkalies become effervescent; strontia, barytic and lime-waters, acquire a pellicle on being exposed a sufficient time to the action of the air, even upon the highest mountains. Water is likewise always found in the atmosphere, but the quantity of these matters is extremely minute; and experiments are still wanting to prove satisfactorily that carbonic acid gas and water are always and every where present in our atmosphere. The former constituents must therefore be considered as the two substances of which atmospheric air is composed.

Since the nitrogen gas of the atmospheric air cannot be separated by any substance with which chemists are acquainted, the analysis of air can only be attempted by exposing it to the action of those bodies which have the property of abstracting its oxygen. The oxygen gas being separated, the nitrogen is left behind, and the proportion of oxygen may be ascertained by the diminution of bulk, which once known, it is easy to determine the exact relative quantity of the component parts.

ANALYSIS OF ATMOSPHERIC AIR.

Experiment I.

Fasten a straight piece of wax taper, about four inches long, upon a cork, then take an empty wine bottle, and hold it by the neck in an inverted position; light the taper, and introduce it quickly into the mouth of the bottle; push in the cork in order to prevent the entrance of any air from without. The flame of the taper will burn well at first, but in a few minutes it will contract, grow dim, and at last be extinguished.

If now the taper be quickly withdrawn, the mouth of the bottle being closed with the thumb, and the taper lighted again and introduced into the bottle, it will be immediately extinguished.

On introducing the bottle in an inverted position into a basin of water, and then withdrawing the cork, the water will ascend into the bottle and fill the place of the air which has been lost.

The following experiment will further illustrate this fact.

Experiment II.

Take a florence flask, holding about a pint, put into it three or four grains of phosphorus, and cork it air-tight. Having done this, heat it gradually over a lamp. As soon as the phosphorus has been heated to a certain degree it takes fire, burning with a flame and a dense white smoke; but as it soon ceases to burn, heat the vessel again, after it has cooled, to try if any more combustion will take place; lastly, let the flask cool.

If the vessel was perfectly dry, the inside of it will be

lined with a white coating, but if it was moist this coating will be dissolved into a fluid (phosphoric acid.)

After every thing has returned to its former temperature, plunge the flask inverted under water and draw out the cork; the water will ascend in it: hence a portion of the air it contained *has disappeared.*

The water which has risen shows what quantity of air has been lost, if its cubic contents be compared with that of the whole vessel. The portion of air thus vanished will in general amount to about one-fifth of the whole that had been submitted to the experiment.

If the flask, after the phosphorus was enclosed in it, be accurately weighed, and again after the combustion has taken place, no difference of weight will be found.

The water forced [redacted] into the vessel changes the blue tincture of cabbag[redacted]e to red; an evident proof of the presence of an acid.

The remaining air is unfit for burning phosphorus or other bodies; animals are likewise suffocated in it.

RATIONALE....Phosphorus is a simple body: on being heated it analyses the atmospheric air, that is to say, the equilibrium of the affinity subsisting between the compound parts of the air, namely, the oxygen and the nitrogen, is broken, on account of the phosphorus having a greater attraction for the oxygen than the nitrogen has, it therefore unites to it, and becomes by this addition converted into an acid, called phosphoric acid: the other part of the atmosphere remains behind. The light and heat which are liberated during the combustion arise both from the oxygen gas and the phosphorus.

EXPERIMENT III.

Take a piece of lead or any other material considerably heavier than water, fasten into it perpendicularly metal wires of different lengths; affix tapers to the extremities of these wires, and place the stand in the middle of a flat dish or basin half filled with water. Then light the tapers (which should differ in height five or six inches) and cover the whole with a tall cylindrical glass receiver. The tapers will burn during the first few minutes all alike, but after some time the highest one will assume a blue

colour, and the last be extinguished, and the water in the dish will begin to rise; the next taper in height will then burn dull and go out, and the others will be extinguished in succession. The water will rise at the same time considerably up into the glass.

RATIONALE....The philosophy of this experiment is analogous to the former. The burning bodies effect in the confined quantity of atmospheric air a real analysis. They absorb the oxygen it contains and divest it of this principle, leaving the nitrogen gas behind. Combustion therefore consists in the absorption of oxygen gas by a combustible body, the basis of the oxygen being absorbed, and the caloric set at liberty.

SECT. III.

EUDIOMETRY, OR METHODS OF ASCERTAINING THE PURITY OF ATMOSPHERIC AIR.

No sooner was the composition of the atmosphere known, than it became an inquiry of importance to find out a method of ascertaining with facility and precision the relative quantity of oxygen gas contained in a given bulk of atmospheric air.

The instruments in which the oxygen gas of a determined quantity of air was ascertained, received the name of EUDIOMETERS, because they were considered as measurers of the purity of air. They are however more properly called OXYMETERS.

The eudiometers proposed by different chemists are the following:

1. PRIESTLEY'S EUDIOMETER.

The first eudiometer was made in consequence of Dr. Priestley's discovery, that when nitrous gas is mixed with atmospheric air over water, the bulk of the mixture diminishes rapidly, in consequence of the combination of the gas with the oxygen of the air, and the absorption of the nitric acid thus formed by the water.

When nitrous gas is mixed with nitrogen gas, no diminution takes place; but when it is mixed with oxygen gas

in proper proportions, the absorption is complete. Hence it is evident, that in all cases of a mixture of these two gases, the diminution will be proportional to the quantity of the oxygen. Of course it will indicate the proportion of oxygen in air; and by mixing it with different portions of air, it will indicate the different quantities of oxygen which they contain, provided the component parts of air be susceptible of variation.

Dr. Priestley's method was to mix together equal bulks of air and nitrous gas in a low jar, and then transfer the mixture into a narrow graduated glass tube about three feet long, in order to measure the diminution of bulk. He expressed this diminution by the number of hundredth parts remaining. Thus, suppose he had mixed together equal parts of nitrous gas and air, and that the sum total was 200 (or 2.00): suppose the residuum when measured in the graduated tube to amount to 104 (or 1.04) and of course that 96 parts of the whole had disappeared, he denoted the purity of the air thus tried by 104.

REMARK....This method of analysing air by means of nitrous gas is liable to many errors. For the water over which the experiment is made, may contain more or less carbonic acid, atmospheric air, or other heterogeneous substance. The nitrous gas is not always of the same composition, and is partly absorbed by the nitrous acid which is formed; the figure of the vessel and many other circumstances are capable of occasioning considerable differences in the results.

Fontana, Cavendish, Ladriani, Magellan, Von Humbolt, and Dr. Falconer, have made series of laborious experiments to bring the test of nitrous gas to a state of complete accuracy; but notwithstanding the exertions of these philosophers, the methods of analysing air by means of nitrous gas are liable to so many anomalies, that we think it unnecessary to give a particular description of the different instruments invented by them.

2. SCHEELE'S EUDIOMETER

Is merely a graduated glass cylinder, containing a given quantity of air, exposed to a mixture of iron filings and sulphur formed into a paste with water. The substances may be made use of in the following manner :

Make a quantity of sulphur in powder, and iron filings, into a paste with water, and place the mixture in a saucer, or plate, over water, on a stand raised above the fluid; then invert over it a graduated bell-glass, and allow this to stand for a day or two. The air contained in the bell-glass will gradually diminish, as will appear from the ascent of the water.

When no further diminution takes place, the vessel containing the mixture must be removed, and the remaining air will be found to be nitrogen gas, which was contained in that quantity of atmospheric air.

RATIONALE....The moistened sulphur and iron have great affinity to oxygen; they attract and separate it from the atmospheric air, and the nitrogen gas is left behind; the sulphur during the experiment is converted into sulphuric acid, which unites to the alkali and forms sulphate of potash.

The air which is exposed to moistened iron and sulphur gradually becomes diminished, on account of its oxygen combining with a portion of the sulphur which becomes converted into sulphuric acid, and its nitrogen remains behind. The quantity of oxygen contained in the air examined becomes thus obvious, by the diminution of bulk which the volume of air submitted to examination has undergone.

REMARK....The only error to which this method is liable, is that the sulphuric acid which is formed acts on the iron and produces hydrogen gas, which joins to the nitrogen remaining after the absorption, and occasions an incorrect result; and hence it is that the absorption amounts in general to 0.27 parts, although the true quantity of oxygen is no more than from 0.21 to 0.22.

3. DE MARTI'S EUDIOMETER.

De Marti obviated the errors to which the method of Scheele was liable. He availed himself for that purpose of a hydrogenated sulphuret, formed by boiling sulphur and liquid potash, or lime-water, together. These substances, when newly prepared, have the property of absorbing a minute portion of nitrogen gas; but they lose this property when saturated with that gas, which is

easily effected by agitating them for a few minutes in contact with a small portion of atmospheric air.

The apparatus is merely a glass tube, ten inches long, and rather less than half an inch in diameter, open at one end, and hermetically sealed at the other. The close end is divided into 100 equal parts, having an interval of one line between each division. The use of this tube is to measure the portion of air to be employed in the experiment. The tube is filled with water, and by allowing the water to run out gradually while the tube is inverted, and the open end kept shut with the finger, the graduated part is exactly filled with air. These hundred parts of air are introduced into a glass bottle filled with liquid sulphuret of lime previously saturated with nitrogen gas, and capable of holding from two to four times the bulk of the air introduced. The bottle is then to be closed with a ground glass stopper, and agitated for five minutes. After this the stopper is to be withdrawn while the mouth of the phial is under water; and for the greater accuracy, it may be closed and agitated again. Lastly, the air is to be again transferred to the graduated glass tube, in order to ascertain the diminution of its bulk.*

4. HUMBOLT'S EUDIOMETER,

Consists in decomposing a definite quantity of atmospheric air by means of the combustion of phosphorus, after which the portion of gas which remains must be measured.

Take a glass cylinder closed at the top, and whose capacity must be measured into sufficiently small portions by a graduated scale fixed on it. If the instrument be destined solely for examining atmospheric air, it will be sufficient to apply the scale from the orifice of the cylinder down to about half its length, or to sketch that scale on a slip of paper pasted on the outside of the tube, and to varnish it over with a transparent varnish.

This half of the eudiometrical tube is divided into fifty equidistant parts, which in this case indicate hundredth parts of the whole capacity of the instrument.

* Journ. de Phys. LII. 176.

peditious; the apparatus is portable, simple, and convenient.

Take a small glass tube graduated into one hundred equidistant parts; fill this tube with the air to be examined, and plunge it into a bottle or any other convenient vessel, containing a concentrated solution of green muriate or sulphate of iron, strongly impregnated with nitrous gas. All that is necessary to be done is to move the tube in the solution a little backwards and forwards; under these circumstances the oxygen gas contained in the air will be rapidly absorbed; and condensed by the nitrous gas in the solution, in the form of nitrous acid.

N. B. The state of the greatest absorption must be marked, as the mixture afterwards emits a little gas which would alter the result.

This circumstance depends upon the slow decomposition of the nitrous acid (formed during the experiment) by the green oxyd of iron, and the consequent production of a small quantity of aeriform fluid (chiefly nitrous gas) which having no affinity with the red muriate, or sulphate of iron, produced by the combination of oxygen, is gradually evolved, and mingled with the residual nitrogen gas.

The impregnated solution with green muriate is more rapid in its operation than the solution with green sulphate. In cases when these salts cannot be obtained in a state of absolute purity, the common sulphate of iron of commerce may be employed. One cubic inch of moderately strong impregnated solution is capable of absorbing five or six cubic inches of oxygen in common processes; but the same quantity must never be employed for more than one experiment.

GENERAL REMARKS.

In all these different methods of analysing air, it is necessary to operate on air of a determinate density,* and to take care that the residuum be neither more condensed nor dilated than the air was when first operated on. If these things are not attended to, no dependence whatever can be placed upon the result of the experiments, how carefully soever they may have been performed. It is

* Hence the necessity of noting the state of the barometer and thermometer. T. C.

therefore necessary to place the air before and after the examination into water of the same temperature. If this and several other little circumstances have been attended to, for instance a change in the height of the barometer, &c. we find that air is composed of 0.22 of oxygen gas, and 0.78 of nitrogen gas by bulk. But as the weight of these two gases is not exactly the same, the proportion of the component parts by weight will differ a little; for as the specific gravity of oxygen gas is to that of nitrogen gas as 135 : 115, it follows that 100 parts of air are composed *by weight* of about

74 nitrogen gas
26 oxygen gas

100

The air of this metropolis, examined by means of Davy's eudiometer, I found in all the different seasons of the year to contain 0.21 of oxygen; and the same was the case with air taken at Islington and Highgate, in the solitary cells in Cold-bath-fields prison, on the River Thames, and at Brighton. But the quantity of water contained in a given bulk of air from these places differed considerably.

Having thus ascertained the nature and the proportion of the component parts of air, it remains only to inquire in what manner these component parts are united. Are they merely mixed together mechanically, or are they combined chemically? Is air a mechanical mixture or a chemical compound? Philosophers seem at first to have adopted the former of these opinions, if we except Scheele, who always considered air as a chemical compound. But the supposition that air is a mechanical mixture, by no means agrees with the phenomena which it exhibits. If the two gases were only mixed together, as their specific gravity is different, it is scarcely possible that they would be uniformly mixed in every part of the atmosphere. Since therefore air is in *all places* composed of the same ingredients, exactly in the same proportions, it follows that its component parts are not only mixed, but actually combined.* When substances differing in specific gravity combine together, the specific gravity of the compound is

* For the specific gravity of oxygen is to that of nitrogen, as 1.103, to 0.969. T. C.

usually greater than the mean. This holds good also with respect to air. The specific gravity, by calculation, amounts only to 0.00119, whereas it actually is 0.0012.

We must therefore consider air as a chemical compound. Hence the reason that it is in all cases the same, notwithstanding the numerous decomposing processes to which it is subjected. The breathing of animals, combustion, and a thousand other operations, are constantly abstracting its oxygen, and decomposing it. The air thus decomposed or vitiated, no doubt, ascends in the atmosphere, and is again, by some unknown process, re-converted into atmospheric air. But the nature of these changes is at present concealed under an impenetrable veil.*

* Atmospheric air supports life and combustion by means of its oxygen. When inspired, a part of the oxygen is absorbed by the blood, and a part converted into carbonic acid by the carbon given out from the blood. Atmospheric air is absorbed by water, from which it can be expelled by boiling. T. C.

CARBONIC ACID GAS.

PART XIX.

SECT. I.

CARBONIC acid gas is the first elastic aeriform fluid that was known. We find that the ancients were in some measure acquainted with it. Van Helmont called it the gas of Must, or of the vintage, or *gas sylvestre.*

We are indebted to Dr. Black of Edinburgh for the knowledge of some of the most remarkable properties of this fluid. In the year 1755 he discovered the affinity between this gas and the alkalies: and Bergman, in 1772, proved that it was an acid.

PROPERTIES OF CARBONIC ACID GAS.

Carbonic acid gas is invisible. It extinguishes flame. It is fatal to animal life. It exerts powerful effects on living vegetables. Its taste is pungent and acid. Its energy, as an acid, is but feeble, although distinct and certain. Neither light nor caloric seems to produce any distinct effect upon it, except that the latter dilates it. It mixes without combining with oxygen gas. It unites with water slowly. These two fluids, after considerable agitation, at last combine, and form a sub-acid fluid. The colder

the water, and the greater the pressure applied, the more carbonic acid gas will be absorbed. The water impregnated with it sparkles upon agitation; it has a pungent, acidulous taste, and reddens tincture of litmus. Heat again disengages the gas from the water. This gas precipitates lime, strontia, and barytes, from their solutions in water. It is greedily attracted by all the alkalies. It undergoes no alteration by light. Its specific weight is to that of atmospheric air as 1500 to 1000. It may be poured out of one vessel into another. It is not acted upon by oxygen, nor is it altered by any of the simple combustible bodies at common temperatures; but phosphorus, iron, and lime, are capable of decomposing it when assisted by heat.

METHODS OF OBTAINING CARBONIC ACID GAS.

Of all the gases, carbonic acid gas is that, perhaps, which is diffused in the greatest abundance throughout nature. It is found in three different states: 1*st*, In that of gas; 2*dly*, In that of mixture; and 3*dly*, In that of combination. The various processes of obtaining it are the following:

1. Put into a common gas-bottle, or retort, a little marble, chalk, or lime-stone, and pour on it sulphuric acid, diluted with about six times its weight of water; an effervescence will ensue, and carbonic acid gas will be liberated, which those who have an opportunity may collect over mercury; but a mercurial apparatus is not absolutely necessary, since the gas may be collected over water, if it is to be used immediately when procured.

Rationale....In this instance the carbonic acid is disengaged from the state of combination, and reduced to the aeriform state of gas. The marble, lime-stone, or chalk, consists of this acid and lime; on presenting to it sulphuric acid, a decomposition takes place: the sulphuric acid has a greater affinity to the lime than the carbonic acid has; it therefore unites to it, and forms sulphate of lime, disengaging at the same time the carbonic acid in the state of gas at the temperature of our atmosphere.

Remark....Carbonic acid gas may in this manner be disengaged from all its combinations with alkalies; by

using indifferently any other dense acid, possessing a superior affinity to the alkali in the common acceptation of the word.

2. It may likewise be obtained from the same substances by the action of caloric.

For this purpose reduce marble or chalk to powder, introduce it into a gun barrel, which must be placed across the universal furnace, adapt a bent tube to its lower extremity, and insert it below a receiver in the pneumatic apparatus. Maintain a strong heat till the barrel is brought to a state of ignition, and at that temperature carbonic acid gas will be liberated in abundance.

RATIONALE....In this case a decomposition of the marble or carbonate of lime takes place, on account of the action of caloric, which at a high temperature breaks the affinity of the carbonic acid and lime; it unites with the first, and leaves the lime behind in that state which is generally called quick lime.

3. Carbonic acid gas may also be obtained by burning charcoal in oxygen gas. We have already mentioned this, but we shall here give directions how it is best effected.

Take a bell glass, filled with oxygen gas, resting inverted in a basin of mercury; pass up into it some bits of new made charcoal, with some touch paper affixed to them; set fire to them by means of a lens collecting the sun's rays, and carbonic acid will be produced by the combustion of the charcoal.

The rationale of this experiment has been given, page 230.

Carbonic acid gas is often found occupying the lower parts of mines, caverns, tombs, and such other subterraneous places as contain materials for producing it. It is called choke, or chalk damp. The grotto del Cane, near Naples, has long been famous for the quantity of carbonic acid gas produced there, which runs out at the opening like a stream of water. The quantity of carbonic acid gas generated in this cavern is so great, that a dog or any other animal is immediately killed if his nose be thrust into it.*

* But as by its weight it does not rise speedily, a man's head is above it, and therefore though a dog will be effected by it in that grotto, a man will not by merely going in. T.C.

The carbonic acid, existing naturally in a state of gas, may be collected by filling bottles with water and emptying them in the atmosphere of this gas; the gas takes the place of the water, and fills the bottles, which must then be corked.

Carbonic acid gas is likewise formed during fermentation; on account of its great weight, it occupies the apparently empty space, or upper part of the vessel in which the fermenting process is going on. It may in this case be collected in a manner similar to that above.

Carbonic acid gas is also obtained during respiration, during the reduction of metallic oxyds, and during the deflagration of nitrates with combustible bodies, as shall be noticed in another part of this work.

It contains 13 parts carbon, 34 parts oxygen.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF CARBONIC ACID GAS.

Experiment I.

Carbonic acid gas is unfit for combustion.

To prove this, set a vessel filled with this gas with its mouth upwards, and let down a lighted candle; the candle will be immediately extinguished, and the smoke remaining in the gas will render its surface visible, which by agitation may be thrown into undulating waves.

The following experiment will show this property in a pleasing manner.

Experiment II.

Take three glass tubes, of equal heights, and fill the first with atmospheric air, the second with carbonic acid gas, and the third with oxygen gas; plunge successively, and with swiftness, a lighted taper into these three tubes; first into that containing atmospheric air, then into the tube filled with carbonic acid gas, and lastly into that filled

with oxygen gas. In the tube filled with atmospheric air, the taper will burn with its usual brightness; in that filled with carbonic acid gas, the flame will be suddenly extinguished, but the glowing wick will be re-lighted in the tube containing oxygen gas, and burn with a dazzling splendour.

RATIONALE....This experiment confirms a fact already established; namely, that oxygen gas is much fitter for combustion than atmospheric air; and is also a most complete proof that carbonic acid gas extinguishes light.

REMARK....This property of carbonic acid gas may be advantageously made use of to learn whether the air in a newly sunk well, in subterraneous caverns, pits, mines, vaults, cellars, and the like, may be approached without danger.

EXPERIMENT III.

Carbonic acid gas is fatal to animal life.

Put a mouse or other small animal into a vessel filled with this gas, and cover the vessel, to prevent the contact of atmospheric air. The animal will die in a minute or two.

REMARK....It is this gas which has produced so many fatal accidents, at the opening of cellars or vaults, in which wine, cider, or beer, has been suffered to ferment.

The famous lake of Averno, where Virgil placed the entrance of hell, yields so large a quantity of carbonic acid gas, that birds cannot fly close over it with impunity.

EXPERIMENT IV.

*Carbonic acid gas is heavier than atmospheric air.**

Let a long glass tube proceeding from a gas-bottle in which carbonic acid gas is disengaging be twice bent at right angles. Let the open end of the longest leg reach to the bottom of a jar, perfectly dry within, and standing with its mouth uppermost. The carbonic acid disengaged will expel the atmospheric air from the jar, on account of its greater specific gravity. When the jar is filled with the gas (which may be known by a lighted candle being

* Atmospheric air being 1, carbonic acid gas according to Biot and Arago, is 1,5196. T. C.

instantly extinguished in it a little below the brim) take another jar of rather a smaller size, and place at the bottom of it a lighted taper or a small animal, and pour the invisible contents of the first jar into the second (in the same manner as if water was poured) the candle will be immediately extinguished, or the animal will die; though the eye is incapable of perceiving any thing poured upon them capable of producing this effect.

Experiment V.

Carbonic acid gas is absorbable by water.

(*See Appendix No.* 24.)

Fill a jar partly with this gas, and let it stand for some hours over water; an absorption will gradually take place, till at last none of the gas remains. If this be repeated, with this difference, that the jar be shaken strongly, a very rapid diminution will take place.

Remark....Water may be charged with upwards of three times its own bulk of carbonic acid gas, if pressure be applied. The water thus impregnated has a very brisk and pleasant taste. Various kinds of apparatus are employed for this purpose. A machine has been invented by Dr. Nooth, and improved by Parker and Magellan, which is convenient and ingenious; but it is impossible to impregnate water by its means with more than half its own bulk of carbonic acid gas. The valve of this machine is the most defective, and renders it extremely apt to break: for the capillary tube does not admit the air through it, unless there be a considerable quantity condensed in the lower vessel, and the condensation is apt to burst the vessel. Other apparatus, more simple, have been invented by different persons, descriptions of which may be found in Scherer's Journal der Chimie; in the Transactions of the Manchester Philosophical Society; and in Bouillon La Grange's Manual of Chemistry, vol. I. p. 93.

Cider, perry, ale, champaign, &c. owe their briskness to the carbonic acid gas which they contain, and which becomes rapidly disengaged in order to assume the gaseous form, on removing the cork of the bottle; it is this also which produces froth, &c.

Experiment VI.

Carbonic acid gas when combined with water possesses acid properties.

This may be shown by dipping into water saturated with carbonic acid gas a piece of litmus paper, or by mixing with it about an equal quantity of infusion of cabbage. The blue colour of the paper or infusion will be changed to red.

Experiment VII.

Carbonic acid gas precipitates lime, barytic, and strontia water.

Let the stream of carbonic acid gas, as it proceeds from the disengaging vessel, pass into either of these solutions, the fluid, though perfectly transparent before, will instantly grow turbid, and carbonate of lime, barytes, or strontia, will be formed.

If equal measures of water impregnated with carbonic acid gas, and either of the above solutions be mixed, a similar effect will be produced.

Experiment VIII.

Carbonic acid gas exerts powerful effects on living vegetables.

Water impregnated with carbonic acid gas proves highly nutritive, when applied to the roots of plants. But, on the contrary, carbonic acid gas applied as an atmosphere, by confining living vegetables in it, proves injurious to the health of the plants, especially in the shade.

This may be proved by confining a small plant in a vessel filled with the gas. The plant will soon decay and die.

Rationale....In the first case, where water is present, the carbonic acid is decomposed, the carbonaceous principle fixes itself into the vegetable, becoming a component part of it, the oxygen which held the carbon in solution is therefore disengaged in a gaseous state. In the latter instance no such effect takes place.

Experiment IX.

Carbonic acid gas is rapidly absorbed by alkalies, and alkaline earths.

Fill a tube with this gas over water, and when full invert it in a cup containing a concentrated solution of potash, or any other alkali; the solution will rise in the tube, and if the gas be very pure will fill it entirely.

Rationale....This absorption of the gas is owing to the alkali uniting with the carbonic acid gas, and forming with it a saline compound, called carbonate of potash.*

* It unites and forms neutral salts with the alkalies, the alkaline earths and most metals. T. C.

LIGHT

CARBONATED HYDROGEN GAS.

PART XX.

SECT. I.

It was mentioned before that hydrogen gas has the property of dissolving various substances in minute quantities, such as carbon, sulphur, phosphorus, &c. The nature of the gas now under consideration furnishes an instance of this kind. Light carbonated hydrogen gas is hydrogen gas holding charcoal in solution. There are several combinations of this kind of gas obtained by different processes, which differ in their properties, and in the proportion of their constituent principles.

PROPERTIES OF LIGHT CARBONATED HYDROGEN GAS.

Light carbonated hydrogen gas has a fetid odour. It is neither absorbed nor altered by water. It is inflammable, and burns with a denser and deeper coloured flame than hydrogen gas. It is unalterable by acids or alkalies, and by water. Its specific gravity is greater than that of hydrogen gas, or that of common air. Its combustion with a due proportion of oxygen gas is productive of water and carbonic acid. When passed through melted sulphur, it becomes converted into sulphurated hydrogen gas, and charcoal is deposited. Electrization dilates it permanently to a little more than twice its original bulk. The air thus

expanded requires a greater quantity of oxygen to decompose it than the same quantity of gas not dilated by electricity; 100 cubic inches of pure carbonated hydrogen gas weigh from 16 to 21 grains.

METHODS OF OBTAINING LIGHT CARBONATED HYDROGEN GAS.

Light carbonated hydrogen gas may be obtained from animal, vegetable, or mineral substances. Nature produces it ready formed in marshes and ditches, on the surface of putrid water, in burying places, common sewers, and in those situations where putrid animal and vegetable matters are accumulated. It is also generated in the intestinal canal of living animals.

1. Light carbonated hydrogen gas may be plentifully procured from most stagnant waters: to do this fill a wide mouthed bottle with the water, and keep it inverted therein, with a funnel in its neck: then with a stick stir the mud at the bottom just under the funnel in the bottle, so as to let the bubbles of air which rise from the mud enter into the bottle; when, by thus stirring the mud in various places, and catching the air in the bottle, it is filled, it must be corked under water.

2. It may also be obtained during the distillation of animal and vegetable matters. For instance,

Let shavings of wood or saw-dust be put into a retort, and begin the distillation with a gentle heat, increasing it gradually till the retort becomes red hot; a great quantity of gas will be liberated, which may he caught over water.* On examining this gas, it will be found to consist of carbonic acid gas and carbonated hydrogen gas. In order to obtain the latter in a state of purity, the whole must be mixed with lime water, or with a caustic alkaline solution. The carbonic acid gas will be absorbed, and the carbonated hydrogen gas left behind in a pure state.

RATIONALE....The production of this gas in this manner is the result of a partial analysis of the wood: it proves that wood contains solid hydrogen, carbon, and oxygen. When the intensity of the heat has reached a certain degree, a part of the charcoal unites with part of the oxygen, and produces carbonic acid, which by means of

* I procured 12 quarts of gas from 4 ounces of pine saw dust; and about 19 quarts from 4 ounces of Liverpool coal. T. C.

caloric is melted into the gaseous state, and forms carbonic acid gas; at the same time, a part of the hydrogen of the wood combines with another portion of carbon and caloric, and forms carbonated hydrogen gas.

REMARK....The flame of burning wood, &c. is the inflamed carbonated hydrogen gas, liberated on the application of caloric to such bodies.

3. Charcoal is in general made use of for obtaining light carbonated hydrogen gas. For this purpose, put some moistened charcoal into an earthen retort, apply heat, and increase it till the retort becomes ignited; gas will be evolved, consisting partly of carbonic acid gas, and partly of light carbonated hydrogen gas, which may be separated as before.

RATIONALE...In this case a decomposition of the water, takes place, by means of the charcoal. The oxygen forsakes its hydrogen, and unites to part of the charcoal at this temperature, and forms carbonic acid gas, in conjunction with caloric; the liberated hydrogen, assisted by caloric, dissolves another portion of the charcoal, and forms with it light carbonated hydrogen gas.

4. Light carbonated hydrogen gas may be formed in a direct manner by dissolving charcoal in hydrogen gas. This may be effected by directing the rays of the sun, collected in the focus of a mirror, upon a small piece of charcoal placed on mercury, in a receiver filled with hydrogen gas.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF LIGHT CARBONATED HYDROGEN GAS.

EXPERIMENT I.

Light carbonated hydrogen gas is inflammable.

This may be shown by filling a tumbler, or any wide-mouthed vessel, with this gas, and setting fire to it, by means of a lighted taper. It may likewise be shown by burning it in the manner directed for burning hydrogen gas. The colour of the flame of this gas is of a deeper blue than that of hydrogen gas.

Experiment II.

Light carbonated hydrogen gas is heavier than hydrogen gas.

Soap bubbles blown in it do not ascend like those filled with hydrogen gas, but descend like those filled with common air. A jar filled with carbonated hydrogen gas, held inverted for a few minutes, exchanges its contents for common air.

Experiment III.

Decomposition of light carbonated hydrogen gas, by means of oxygen gas.

Mr. Cruikshank found (Nicholson's Journal, April, 1801) that six measures of carbonated hydrogen gas obtained from moistened charcoal, when mixed with four of pure oxygen gas, over mercury, exploded violently by the electric spark, and became augmented to $12\frac{1}{2}$ measures, or that there was an increase of $2\frac{1}{2}$ measures nearly. On admitting lime-water, the volume diminished rather more than two measures; the residue amounted to $10\frac{1}{4}$, on which nitrous gas had no effect. Two measures of the residuary gas fired with one of oxygen became reduced to one, which was carbonic acid gas. Hence the whole residuary gas would require about $5\frac{1}{4}$ measures of oxygen to saturate it, and produce 5 measures of carbonic acid gas.

Experiment IV.

Decomposition of light carbonated hydrogen gas, by means of oxygenated muriatic acid gas.

The effects of the oxygenized muriatic acid gas upon all the hydro-carbonates is remarkable. Mr. Cruikshank observed, that if the pure oxygenized muriatic acid gas be mixed with these kinds of gases over water, although no action should be perceptible at first, yet in twenty-four hours a complete decomposition and change of principles takes place.

For instance, introduce into a bottle filled with and inverted over water one measure of pure light carbonated

hydrogen gas well washed, mixed with two measures of fresh-prepared pure oxygenized muriatic acid gas. On the first contact of the oxygenized muriatic acid gas, a white cloud and some diminution will be perceived, which will soon cease. The bottle must then be stopped, and suffered to remain inverted in water for about twenty-four hours. If the bottle be then uncorked under water, this fluid will instantly ascend into it, and the gas will occupy about .43 parts of a measure, the diminution being 2.57 measures. On mixing the residuary gas with lime-water, .09 parts more become absorbed.

RATIONALE....The results obtained in this experiment with the pure light carbonated hydrogen gas are very easily understood; for it is evident that the oxygenized muriatic acid gas gives out its excess of oxygen to the carbon and hydrogen of the inflammable gas from a superior affinity; in consequence of which, we have no less than four new compounds. Part of the oxygen of the oxygenized muriatic acid gas joins to the hydrogen of the carbonated hydrogen gas, and forms water; another part unites to the charcoal, and produces carbonic acid gas; a still less quantity combines with another portion of charcoal, and forms gaseous oxyd of carbon; and the oxygenized muriatic acid gas, by thus losing its excess of oxygen, becomes converted into simple muriatic acid gas.

REMARK....According to Mr. Cruikshank's experiments, 100 cubic inches of light carbonated hydrogen gas, obtained from wetted charcoal, weighed 14.5 grains; they required 66 cubic inches (22.4 grains) of oxygen to saturate them. The compound yielded 40 cubic inches (19 grains) of carbonic acid, and nine grains of water. Hence this gas consists of nearly 4 of carbon, 1.3 of hydrogen, and 9 of water.

HEAVY

CARBONATED HYDROGEN GAS.

PART XXI.

SECT. I.

THIS gas was first brought into notice by a society of Dutch chemists, consisting of Deiman, Troostwyk, Bond, and Laurenburgh. They observed in this gas the particular property, that when it was combined with oxygenated muriatic acid gas in a certain proportion the elastic form of both fluids became destroyed, and an oil was produced; for which reason they called it *olefiant gas*.

PROPERTIES OF HEAVY CARBONATED HYDROGEN GAS.

Heavy carbonated hydrogen gas is not absorbed or altered by water. Its weight compared with common air is as 909 to 1000. It has a disagreeable fetid odour, different from that of light carbonated hydrogen gas. It burns with a strong compact flame, similar to that of a resinous oil. When mixed with oxygenized muriatic acid gas its bulk is diminished, and an oil is formed. When the mixture of these two gases is fired, a quantity of charcoal is immediately deposited in the form of fine soot. Sulphuric, sulphureous, nitric, nitrous, and muriatic acids do not act upon it; neither does nitrous gas, nor any of the fixed alkalies. Ammonia adds to its volume without

occasioning any other change. Phosphorus heated in it even to fusion does not affect it. When made to pass through an ignited glas tube, it does not diminish in volume, but loses the property of forming oil with oxygenized muriatic acid gas. Electric shocks passed through it dilate, and likewise deprive it of this property. When passed through an ignited porcelain tube, it affords hydrogen gas, mingled with carbonic acid, and carbon is deposited. When passed through a tube with sulphur in fusion, sulphurated hydrogen gas is obtained, and charcoal deposited. When burnt with oxygen gas, or when passed through a red-hot tube filled with oxyd of manganese, carbonic acid gas is formed.

METHODS OF OBTAINING HEAVY CARBONATED HYDROGEN GAS.

Heavy carbonated hydrogen gas is obtained by decomposing alcohol by sulphuric acid at high temperatures. It is also obtained in abundance when alcohol or ether is passed through a red-hot earthen tube. Sulphuric ether, mixed with sulphuric acid, and subjected to heat, also affords it, but in a less pure state.

The Dutch chemists observed, that if the vapour of ardent spirit or ether be made to pass through a glass tube, over the component parts of the earthen tube, namely, alumine and silex, this gas was also produced, or by passing it through a red-hot tube of pipe-clay.

In order to obtain this gas, the following method may serve:

Let four parts by weight of concentrated sulphuric acid and one of highly rectified ardent spirit be mingled together gradually in a glass retort, heat will be developed, the mixture will become brown, and heavy carbonated hydrogen gas will be extricated by the application of heat. When a moderate heat is applied, the action is very violent, and the gas is liberated very copiously, and may be received over water.

The gas obtained is always mixed with a considerable quantity of sulphureous acid gas, from which it may be freed by agitating it in contact with lime-water, or a solution of potash.

REMARK....In this operation the heat ought to be regulated with great care, and the retort holding the mixture ought to be very capacious, otherwise the matter will be forced over into the receiver. The heat of a candle or lamp is sufficient.

Numerous experiments by different chemists have proved, that this species of carbonated hydrogen gas contains a larger quantity of carbon in solution than the former. This becomes obvious from the gas losing the property of forming oil, by being made to pass through an ignited tube; for it then deposits charcoal, and becomes converted into light carbonated hydrogen gas.

The Dutch philosophers suppose, that the disposition to form oil depends on the proximity of the constituent moleculæ of the gas; and the loss of this property they suppose to be owing to the separation of these moleculæ, by the introduction of a greater quantity of caloric.

Heavy carbonated hydrogen gas, they say, is converted into light carbonated hydrogen gas whenever a process is executed which increases the distance subsisting between its component parts. In this way the attraction betweeen the particles of the hydrogen and carbon is diminished, which happens whenever the gas is made to pass through ignited tubes, capable of acquiring a high temperature, or by strongly electrifying it.

Either heavy or light carbonated hydrogen gas may therefore be obtained indiscriminately from the same substances, namely ether or ardent spirit. Their difference arises from different methods of treating these fluids, and is constantly reducible to this; that in forming the first gas a less quantity of caloric acts upon the mass, and a compound is formed, in which the hydrogen and charcoal are more concentrated, and more disposed to form oil by the addition of oxygen; whereas by more strongly heating the ardent spirit or ether, they become more completely decomposed; their constituent parts are removed to a greater distance, by a greater proportion of caloric being introduced between them; and the simultaneous attraction, which might be disposed to form oil with oxygen, is so far diminished, that they are no longer capable of that transition, therefore no oil can be formed.

Hence we perceive, likewise, why the specific gravity of the heavy carbonated hydrogen gas, when it loses its property of forming oil, becomes diminished.

We do not however agree with the Dutch chemists, that either the alumine, silex, or earthen tube serves to form this gas, as they assert, while glass tubes only afford the common carbonated hydrogen gas. These different effects certainly do not arise from the causes which are assigned to them. They seem to arise from a less degree of heat having been applied in all the cases where the heavy carbonated hydrogen gas was produced, and a greater degree in all those which present the light carbonated hydrogen gas.

Mr. Nicholson observed,* that when ardent spirit is burnt in the lamp of Argand, and the lower aperture or air passage of the lamp is kept open, the flame of the spirit is as usual faint and bluish, resembling that of carbonated hydrogen gas; but if the air passage be obstructed, by slowly applying the palm of the hand, or any more suitable obstacle, the flame becomes more and more luminous, like that of oil, until in the progress of obstruction the aperture is so much closed that the combustion begins to decay for want of air. By a proper adjustment of the aperture, the spirit may be made to burn with a constant luminous white internal flame. In this case the temperature is precisely such as to produce the olefiant gas.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF HEAVY CARBONATED HYDROGEN GAS.

The properties of this gas being similar to those of the other hydro-carbonates, it is unnecessary to exhibit experimental proofs of them; those already advanced under the head of light carbonated hydrogen gas will explain them all, with the exception of its characteristic property of producing oil with oxygenized muriatic acid gas, which shall be inserted here, with a few other interesting remarks.

* Journal of Natural Philosophy, &c. May, 1797, p. 55.

Experiment I.

Production of oil by the mixture of heavy carbonated hydrogen gas with oxygenated muriatic acid gas.

Take a glass tube, send up into it three parts of *fresh prepared* heavy carbonated hydrogen gas, and add to it gradually four parts of *fresh prepared* oxygenized muriatic acid gas. After each addition of the gas, shake the mixture; an absorption will take place, caloric will be liberated, and the tube will become filled with white vapours. When the gases have totally disappeared, an oil of a pearl gray colour will be deposited.

This oil is heavier than water, its odour is agreeable and penetrating, its taste is rather sweet; it becomes yellow by exposure to air.

Experiment II.

Conversion of heavy carbonated hydrogen gas into light carbonated hydrogen by combustion with oxygen gas.

Let equal parts of fresh prepared heavy carbonated hydrogen gas and oxygen gas be mingled together in a detonating tube, and a spark be passed through it, a momentary expansion will take place, the tube will become lined with a fine black soot of charcoal, and the heavy carbonated hydrogen gas will thus be converted into light carbonated hydrogen gas.

Mr. Cruikshank found that 100 cubic inches of carbonated hydrogen gas, obtained from alcohol, weighed 16 grains: it required 118 cubic inches of oxygen to saturate it, and produced 75 cubic inches of carbonic acid. This gas therefore consists of 7 carbon, 1.9 hydrogen, and 7 water.

The same quantity of gas obtained from ether weighed 20 grains: it required for saturation 170 cubic inches of oxygen, and produced 108 of carbonic acid. Hence this gas consisted of 9 carbon, 3 hydrogen, and 8 water.

One hundred cubic inches of carbonated hydrogen gas, obtained from camphor, weighed 21 grains. They consumed 176 cubic inches of oxygen, and produced 116 of

carbonic acid; this gas consisted therefore of 11 carbon, 2 + hydrogen, and 8 or 9 of water.

In the preceding estimate, the weight of 100 cubic inches of common air, under the mean pressure of the atmosphere, and at the temperature of 55°, is estimated at 31 grains. The quantity of carbon in carbonic acid at $\frac{1}{3}$ of the whole nearly, and the proportion of oxygen to hydrogen in water as about 85 to 15.

From the result of these experiments we perceive that the carbonated hydrogen gases obtained from various substances differ in their composition. This has given rise to the next species of gas.

GASEOUS OXYD OF CARBON.

PART XXII.

GASEOUS oxyd of carbon was first described by Dr. Priestly, who mistook it for a hydro-carbonate.

With the true nature of it we have been only lately acquainted. It was first proved to be a peculiar gas by Mr. Cruikshank of Woolwich, who made it known to us, as such, in April 1801, through the medium of Nicholson's Journal for that month. Several additional properties of this gas were soon afterwards noticed by Desormes, Clement, and others. Gaseous oxyd of carbon forms an intermediate substance between the pure hydro-carbonates and carbonic acid gas; but not being possessed of acid properties, Mr. Cruikshank has called it, conformable to the rules of the chemical nomenclature, *gaseous oxyd of carbon*, for it consists of oxygen and carbon rendered gaseous by caloric.

Though the gaseous oxyd of carbon has some of the properties peculiar to the common hydro-carbonates, the following characteristic properties sufficiently prove that none of those at present known are similar to it. We are therefore entitled to consider it as a gas peculiar to itself.

SECT. I.

PROPERTIES OF GASEOUS OXYD OF CARBON.

GASEOUS oxyd of carbon is considerably lighter than any of the hydro-carbonates. It is lighter than common

air in the proportion of 22 to 23. When mingled with common air and ignited, it does not explode, but burns with a lambent blue flame, and the product is carbonic acid. It is very little absorbable by water; it is void of taste and odour. A mixture of 20 parts of gaseous oxyd of carbon and 8 of oxygen gas, fired over mercury by electricity, diminishes to a volume equal to about 18 or 19 parts, which is carbonic acid gas. It contains neither water nor the basis of that fluid. It is exceedingly noxious; animals die in it instantly; when breathed for a few minutes only, it produces giddiness and fainting. Neither light, heat, nor electricity have any effect upon it. When equal quantities of gaseous oxyd of carbon and hydrogen gas are passed through a red hot glass tube, the tube is lined with charcoal, water is formed, and an excess of hydrogen makes its escape. If a piece of iron be put into the tube, it is oxydated, but not converted into steel. Neither nitrogen gas nor sulphur have any action on it, even at high temperatures. It is capable of dissolving a minute quantity of charcoal, and increases in bulk. It dissolves phosphorus, and acquires the property of burning with a yellow flame. The alkalies have no effect on this gas. It is not altered when passed with ammonia through an ignited tube. When the red oxyd of mercury is heated in it, a commencement of reduction takes place. Neither sulphuric, nitric, nor nitro-muriatic acids alter it, when passed with it through a red hot tube. Four parts of oxygenized muriatic acid gas left with one of carbonic acid gas decompose it completely. Nitrous gas has no effect upon it. When mixed with sulphurated hydrogen gas, and passed through a red hot tube, sulphur is deposited, and sulphurated hydrogen gas remains mixed with gaseous oxyd of carbon.

METHODS OF OBTAINING GASEOUS OXYD OF CARBON.

Gaseous oxyd of carbon may be obtained by a decomposition of carbonic acid at high temperatures, by means of various fixed substances which have a considerable affinity to oxygen. This may be done by distilling a mixture of charcoal with any of the metallic oxyds, or by

exposing to a strong red heat a mixture of carbonate of lime or barytes, and filings of iron, zinc, &c.

The method of obtaining the gaseous oxyd of carbon in a state of purity, recommended by Mr. Cruikshank, is the following:

1. Take one part of chalk, previously exposed to a low red heat for about ten minutes. Mix it with an equal quantity of perfectly dry filings of zinc; let the mixture be introduced into a retort, and expose it to a heat gradually increased. As soon as the retort becomes of a dull red heat, gas will be disengaged in great abundance. The gas which comes over first is carbonic acid gas; but as soon as the retort becomes thoroughly ignited, pure gaseous oxyd of carbon is liberated in a prodigious quantity, which may be collected in the usual manner over water.

RATIONALE....In this process a decomposition of the carbonic acid of the chalk takes place in its nascent state. The zinc robs the carbonic acid of part of its oxygen at a high temperature, and becomes to a certain degree oxydated. The carbonic acid, by being thus deprived of part of its oxygen, becomes converted into a new inflammable gas, called gaseous oxyd of carbon.

REMARK....Upon the whole, therefore, we have to consider this gas as holding the same relation to pure hydro-carbonates and carbonic acid gas which nitrous gas or nitrous oxyd does to pure nitrogen and nitrous acid.

Tin, and probably various other metals, when mingled with charcoal, are capable of producing gaseous oxyd of carbon in a similar manner.

2. Gaseous oxyd of carbon may also be obtained in the following manner:

Take equal quantities of scales of iron* separated in forging (black oxyd of iron) and charcoal powder previously heated to redness; mix them together; introduce the mixture into a coated glass retort or gun barrel, and apply heat gradually; as soon as the retort becomes of a dull red heat, gas is produced in great abundance. It consists of about one part of carbonic acid gas and four of gaseous oxyd of carbon. In order to separate the carbonic acid gas, it must be suffered to stand over lime diffused through water, or agitated with lime water; the carbonic acid gas will be absorbed, and what remains behind is pure inflammable

* Usually called smithy-slack.

gaseous oxyd of carbon: or this trouble may be saved, by letting the gas, as it is disengaged, pass through lime, formed into a very thin paste with water. The carbonic acid combines with the lime; but the gaseous oxyd of carbon passes through it unaltered.

RATIONALE....The production of gaseous oxyd of carbon in this manner is in some respects analogous to the former. The black oxyd of iron parts with a portion of its oxygen, which joins to the carbon to form the gaseous oxyd, and another part is liberated in the form of carbonic acid gas. The black oxyd of iron therefore re-approaches to the metallic state.

A mixture of charcoal and oxyd of zinc, red oxyd of copper, semi-vitreous oxyd of lead,* black oxyd of manganese, and the rest of the metallic oxyds capable of enduring a red heat, on being treated with charcoal, also yields carbonic acid gas and gaseous oxyd of carbon. Those oxyds which retain their oxygen most obstinately, yield most of the latter, and those which part with it readily afford most carbonic acid gas. The latter comes over chiefly at the beginning, and the former towards the end of the process.

INFERENCES....From these various facts there can no longer remain any doubt but that the carbonic acid, under certain elevations of temperature, may be decomposed by any fixed substance having a considerable affinity with oxygen; and that, with regard to the metals, those succeed the best which have the greatest attraction for acids or oxygen, as is the case with zinc. Upon the whole we may conclude, that there are but two distinct combinations of carbon and oxygen capable of assuming and maintaining the form of gas: for although the gaseous oxyd of carbon may be obtained in a great variety of ways, by direct composition, as well as during the decomposition of the carbonic acid; yet when pure it is exactly the same substance, having the same specific gravity, requiring the same portion of oxygen to saturate it, and producing the same quantity of carbonic acid, as Mr. Cruikshank† has sufficiently proved experimentally.

* Litharge.

† Nicholson's Journal, Sept. 1801, p. 210.

One hundred cubic inches of gaseous oxyd of carbon, obtained from iron filings and carbonate of lime or barytes, previously ignited, according to Mr. Cruikshank, weigh 30 grains. They require 40 cubic inches (13.6 grains) of oxygen for saturation, and form 92 cubic inches (43.2 grains) of carbonic acid, and no water is produced. Hence the 100 cubic inches of gaseous oxyd of carbon consists of 21 + oxygen 8.6 carbon.

One hundred cubic inches of the same gas, obtained from charcoal and metallic oxyds, weigh 30 grains: they require 44 cubic inches (15 grains) of oxygen for saturation, and yield 76 cubic inches (35.9 grains) of carbonic acid, and afford (on account of the hydrogen contained in the charcoal) about 8 grains of water. Hence this gas consists of about 15 oxygen, 7 carbon, 1 + hydrogen, and an uncertain quantity of water.

Remark....The quantity of oxygen in the gaseous oxyds Mr. Cruikshank estimated thus: in the first instance, for example, we find that 30 grains of the oxyd, combined with 13.6 grains of oxygen, produced 43.3 grains of carbonic acid. This acid consists of 8.6 grains of carbon and 34.6 of oxygen nearly; but the quantity of oxygen employed in the experiment was only 13.6 grains; hence the difference between 34.6 and 13.6 or 21 grains must have been originally contained in the oxyd. It would therefore appear that the gaseous oxyds in their purest state consist of oxygen and carbon, in the proportion of 21 to 9 nearly, combined with caloric.

Upon the whole we consider, as mentioned before, the gaseous oxyd of carbon as holding the same relation to the pure hydro-carbonates and carbonic acid which nitrous gas or nitrous oxyd does to pure nitrogen and nitrous acid.

SULPHURATED HYDROGEN GAS.

PART XXIII.

SECT. I.

PROPERTIES OF SULPHURATED HYDROGEN GAS.

SULPHURATED hydrogen gas possesses the properties of an acid; for, when absorbed by water, its solution reddens vegetable blues; it combines also with alkalies, earths, and with several metallic oxyds. Sulphurated hydrogen gas possesses an extremely offensive odour, resembling that of putrid eggs. It kills animals, and extinguishes burning bodies. When mixed with oxygen gas, or atmospheric air, it is inflammable. Mingled with nitrous gas, it burns with a yellowish green flame. It is decomposed by ammonia, by oxygenized muriatic acid gas, and by sulphureous acid gas. It has a strong action on the greater number of metallic oxyds. Its specific gravity to common air is as 1106 to 1000. It is composed, according to Thenard of 70.857 sulphur and 29.143 hydrogen. It has the property of dissolving a small quantity of phosphorus.*

METHODS OF OBTAINING SULPHURATED HYDROGEN GAS.

1. Take dry sulphuret of potash, put it into a tubulated retort, lodged in a sand bath, or supported over a lamp;

* According to Davy, it contains 6.5 hydrogen and 93.5 sulphur in 100 parts.

direct the neck of the retort under a receiver placed in the pneumatic trough: then pour gradually upon the sulphuret diluted sulphuric or muriatic acid; a violent effervescence will take place, and sulphurated hydrogen gas will be liberated. When no more gas is produced spontaneously, urge the mixture with heat by degrees till it boils, and gas will again be liberated abundantly.

The water made use of for receiving it should be heated to about 80° or 90°: at this temperature it dissolves little of the gas; whereas, if cold water be made use of, a vast quantity of it is absorbed.

RATIONALE....Though sulphur makes no alteration on water, which proves that sulphur has less attraction for oxygen than hydrogen has; yet if sulphur be united to an alkali, this combination decomposes water whenever it comes in contact with it, though the alkali itself has no attraction either for oxygen or hydrogen.

The formation of this gas explains this truth. On adding the sulphuret of potash to the water, this fluid becomes decomposed, part of the sulphur robs it of its oxygen, and forms with it sulphuric acid; this generated acid unites to part of the alkali, and forms sulphate of potash. The liberated hydrogen dissolves another part of the sulphur, and forms with it sulphurated hydrogen; the basis of this gas, which is retained by the separated portion of the alkali. The sulphuric acid added now extricates it from the alkali, and makes it fly off in the form of gas.

The mixture in the retort therefore contains an alkaline sulphure properly so called, or the simple combination of sulphur with alkali; sulphate of potash, and lastly, sulphurated hydrogen gas dissolved in the alkaline sulphure, or an hydrogenated sulphuret.

REMARK....Diluted muriatic acid is best adapted for the production of sulphurated hydrogen gas from alkaline sulphurets. If nitric acid be made use of, it must be much diluted. Sulphuric acid yields little gas, unless assisted by heat. When the proportion of sulphur in the sulphuret exceeds that of the alkali, the dense sulphuric acid poured upon it emits sulphuric acid gas much loaded with sulphur. All the rest of the acids may be made use of for decomposing the sulphurets.

2. When iron and sulphur are united together, they afford a large quantity of sulphurated hydrogen gas on

submitting them to the action of heat, in contact with water.

Melt together in a crucible equal parts of iron filings and sulphur; the product is a black brittle mass called sulphuret of iron. Reduce this to powder, and put it with a little water into a tubulated retort; add diluted muriatic acid, and apply a gentle heat, till no more gas is disengaged.

RATIONALE....The philosophy of this experiment is analogous to the former. Part of the oxygen of the water unites to part of the sulphur, and forms sulphuric acid; another part oxydates the iron, which dissolved by the acid forms sulphate of iron: the hydrogen of the water unites to another part of the sulphur, and forms sulphurated hydrogen, which becomes gaseous by the addition of caloric.

3. Sulphurated hydrogen gas may also be obtained by heating an alkaline sulphuret, with the addition of water, without the affusion of an acid.

RATIONALE....In this case the water is also decomposed; its hydrogen unites with part of the sulphur, and forms sulphurated hydrogen; the oxygen of the water unites with another part of the sulphur and produces sulphuric acid, which joins to the alkali, and forms a sulphate. The sulphurated hydrogen becomes disengaged by heat in the gaseous form.

4. Sulphurated hydrogen gas may be obtained by passing hydrogen gas through sulphur in a state of fusion.

For this purpose put sulphur into a gun-barrel, or Wedgwood's tube, and place it across a furnace; fit to the lower extremity a bent glass tube, which goes under a receiver placed in the pneumatic trough, and adapt to the upper extremity a tubulated retort, or other apparatus proper for producing hydrogen gas. The sulphur must then be heated, and when melted, and the hydrogen gas evolved, must be made to pass over it; which in this manner will dissolve part of the sulphur, and become converted into sulphurated hydrogen gas.

5. It may likewise be procured in a direct manner: for that purpose let a small quantity of sulphur be inclosed in a jar full of hydrogen gas, and melt it by means of a burning glass.

REMARK....This method does not succeed except the hydrogen gas be as dry as possible; for its affinity to sulphur is weakened in proportion to its moisture.*

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF SULPHURATED HYDROGEN GAS.

EXPERIMENT I.

Sulphurated hydrogen gas is absorbed by water.

Fill a bottle with sulphurated hydrogen gas, and keep it inverted in a basin of cold water: an absorption will take place, which may be accelerated by agitation. The water which has absorbed a quantity has the fetid odour of the gas. It is not decomposed by exposure to the air; but the gas is gradually separated and carried off without decomposition. Water impregnated with sulphurated hydrogen gas slightly reddens blue vegetable colours.

REMARK....It is this gas which gives to the mineral waters of Harrowgate and Aix-la-Chapelle their peculiar smell. Such waters may therefore be artificially imitated by impregnating pure water with this gas, and adding the other constituent parts to it. Water absorbs its bulk of this gas.

EXPERIMENT II.

Sulphurated hydrogen gas is inflammable in contact with oxygen gas.

Mix equal parts of sulphurated hydrogen gas and oxygen gas over water, and apply a lighted taper; a smart detonation will take place, and both gases will disappear.

RATIONALE....Part of the oxygen unites to the hydrogen of the sulphurated hydrogen gas; another part joins to the sulphur suspended in this gas: hence the products after combustion are sulphureous acid and water.

* This gas is produced when metals are melted with sulphur, as is said. T. C.

Experiment III.

Sulphurated hydrogen gas mingled with nitrous gas burns with a yellowish green flame.

If three parts of sulphurated hydrogen gas be mixed with two of nitrous gas, the mixture may be inflamed, and burns with a yellowish green flame; the vessel becomes lined with a coat of sulphur.

Rationale....The explanation of these phenomena are analogous to the rationale of the next experiment.

Experiment IV.

Sulphurated hydrogen gas is decomposed by atmospheric air.

Introduce into a bell glass, half filled with sulphurated hydrogen gas, an equal quantity of atmospheric air; a diminution will take place, sulphur will be precipitated, and nitrogen be left behind.

Rationale....The oxygen of the atmospheric air has a greater affinity for hydrogen than the sulphur of the sulphurated hydrogen gas has; they therefore unite and form water, and the sulphur becomes deposited.

Remark....On this principle it is that water holding sulphurated hydrogen gas in solution lets fall sulphur on exposure to the open air; and hence arises the sulphur seen deposited in the channels, and in the neighbourhood of sulphurated, or, as they are commonly called, hepatic waters.

Experiment V.

Sulphurated hydrogen gas becomes quickly absorbed by alkaline solutions.

This may be proved by filling a tube with the gas, and inverting it in a basin containing some concentrated solution of potash. The gas will be absorbed, and the potash will acquire colour, odour, and other peculiar properties.

This combination is called *hydro-sulphuret of potash*; it is a true saline compound.

REMARK....Hitherto only the alkalies and some of the earths have been combined with sulphurated hydrogen gas. These compounds are colourless while kept in close vessels, but when exposed to air they soon acquire colour. This change is produced by the decomposition of part of the sulphurated hydrogen gas by the air. The hydrogen combines with the oxygen of the air, and forms water; while the sulphur is disengaged, and thus darkens the colour.

The sulphurated hydrogen gas may again be expelled from these combinations in the same ratio it had been absorbed, by the addition of an acid. It may also be disengaged by heat.

EXPERIMENT VI.

Sulphurated hydrogen gas and sulphureous acid gas decompose each other.

When sulphurated hydrogen gas and sulphureous acid gas are mingled together over mercury, the volume of the gases becomes diminished, and sulphur is deposited on the sides of the vessel in a considerable quantity.

When these gases are dissolved in water, they mutually undergo the same decomposition. If suitable quantities are taken, the odour of both fluids disappears instantly.

RATIONALE....The hydrogen of the sulphurated hydrogen gas has a greater affinity for the oxygen of the sulphureous acid gas than the sulphur has; they therefore unite and form water, and the sulphur of both is deposited.

REMARK....If concentrated nitrous acid be poured copiously into water holding sulphurated hydrogen gas in solution, sulphur is likewise deposited. Hence nitrous acid is used as a test to detect the presence of sulphurated hydrogen gas in hepatised waters.

EXPERIMENT VII.

Combination of sulphurated hydrogen gas and ammonia.

Fill a glass jar with fresh prepared sulphurated hydrogen gas, confined over mercury, and add to it gradually am-

moniacal gas: a dense white vapour will instantly appear; both gases will vanish; and a white saline compound will be formed, being hydrogenated sulphuret of ammonia.

Experiment VIII.

Oxygenized muriatic acid gas and sulphurated hydrogen gas likewise decompose each other.

Fill a cylindrical vessel over water with oxygenized muriatic acid gas, keep it over that fluid, and mingle it with sulphurated hydrogen gas; at the instant the gases come in contact with each other their bulk will be diminished, and the vessel become lined with sulphur.

Rationale....The oxygen of the oxygenized muriatic acid gas unites partly to the sulphurated hydrogen, and partly to the sulphur dissolved in that gas; hence water and sulphuric acid are formed: the oxygenized muriatic acid gas being robbed of its oxygen becomes converted into simple muriatic acid, and the sulphur which escaped the action of the oxygen is precipitated.

Experiment IX.

Decomposition of sulphurated hydrogen gas by the electric spark.

Fill a detonating tube over water with sulphurated hydrogen gas, and pass the electric spark through it; the volume of the gas will become diminished, and sulphur be precipitated.

Experiment X.

Sulphurated hydrogen gas acts strongly on the greater number of metallic oxyds.

Dip a slip of paper into a solution of silver, lead, bismuth, mercury, tin, &c. and expose it to the action of sulphurated hydrogen gas, the paper will instantly become blackened. Writings performed with these solutions are invisible when dry, but become visible when immersed in a bottle filled with this gas.

RATIONALE....In this instance the hydrogen of the gas abstracts the oxygen from these bodies, and causes them to re-approach to the metallic state; at the same time, the sulphur contained in the gas combines with the metal thus regenerated, and converts it into a sulphuret. (*See Appendix No.* 25.)

PHOSPHORATED HYDROGEN GAS.

PART XXIV.

SECT. I.

WE are indebted to M. Gengembre for the discovery of this gas, which differs from the hydro-carbonates in nothing but the nature of the combustible substance suspended in the hydrogen gas.

Phosphorated hydrogen gas consists of phosphorus dissolved in hydrogen gas.

PROPERTIES OF PHOSPHORATED HYDROGEN GAS.

Phosphorated hydrogen gas is the most combustible* substance in nature. It is particularly distinguished from all other gases, by the property of taking fire immediately when brought in contact with atmospheric air. When mixed with oxygen gas, or with oxygenated muriatic acid gas, it burns with great vehemence. When bubbles of it are suffered to pass through water, they explode in succession as they reach the surface of this fluid. It has an insupportable odour, similar to that of putrid fish. It is partly absorbable by distilled water freed from atmospheric air at low temperatures. Distilled water absorbs about one-fourth, and gives it out again without alteration by heat. Water containing atmospheric air decomposes it, when suffered to stand with it for some time. When exposed to vivid light, it deposits phosphorus in a crystalline form.

* Quere, if it be so much so as equal parts of sulphur and phosphorus. T. C.

METHODS OF OBTAINING PHOSPHORATED HYDROGEN GAS.

1. Take a small retort, put into it one part of phosphorus and ten of a concentrated solution of potash or soda; make the mixture boil, and receive the liberated gas over mercury; or, if it be intended for immediate use, it may be collected over water.

RATIONALE....In this experiment a decomposition of the water takes place. Its oxygen unites to part of the phosphorus, and forms phosphoric acid, which joins to the potash, and forms phosphate of potash. The liberated hydrogen dissolves another part of the phosphorus, and becomes converted into phosphorated hydrogen gas.

REMARK....In thus preparing this gas, the body of the retort should be filled as nearly as possible with the mixture; otherwise the first portion of gas which is produced inflames in the retort; a vacuum is formed; and the water forced up into the retort, and endangers the bursting of it.*

2. Phosphorated hydrogen gas is also obtained, if by a direct exposure to a strong heat we effect a combination of phosphorus and lime, and then throw this compound into water; a great quantity of phosphorated hydrogen gas will soon be formed, and may be obtained in the usual manner over water or mercury.

RATIONALE....The production of phosphorated hydrogen gas in this manner is analogous to the first, with the only difference that here the decomposition of the water takes place at common temperatures.

3. Phosphorated hydrogen gas may also be obtained, according to Davy,† in the following manner:

Let water be decomposed in the usual manner, by means of zinc and sulphuric acid, and add to the mixture a quantity of phosphorus. The hydrogen evolved will dissolve part of the phosphorus; phosphorated hydrogen gas will be produced, and take fire at the surface of the fluid, so long as the decomposition of the water is made, with considerable rapidity. But the gas produced in this

* This may be prevented by removing the beak of the retort when the water ascends: or by burning away the oxygen of the air of the retort with phosphorus: or by filling the retort with hydrogen gas. T. C.

† Nicholson's Journal, April 1802.

process burns with a more lambent flame than that obtained in the usual manner, probably on account of containing a larger quantity of hydrogen. The experiment is nevertheless brilliant; for the gas is disengaged in small bubbles, which cover the whole surface of the fluid; they disengage themselves rapidly, new ones are produced, and the whole fluid resembles a well of fire.

REMARK....For the success of this experiment, it is essential that the water, during the action of its decomposition, be considerably heated, which may be effected by a copious addition of sulphuric acid, and that the phosphorus be present in a considerable quantity. Half a part of phosphorus cut into small pieces, one of granulated zinc, three of concentrated sulphuric acid, and five of water, answer this purpose exceedingly well.

Phosphorated hydrogen gas is also produced by nature. The air which burns at the surface of certain springs, and forms what is called *burning springs* and the *ignis fatui* (Jack o'lanterns) which glide along burying-grounds, or places where animal matters are putrifying, consist of hydrogen gas, holding phosphorus in solution.*

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF PHOSPHORATED HYDROGEN GAS.

EXPERIMENT I.

Phosphorated hydrogen gas takes fire on coming into contact with atmospheric air.

This may be evinced by charging a small retort with potash, phosphorus, and water, in the manner mentioned before, applying heat and dipping the mouth of the retort into a basin of water. The bubbles of air which come from the retort and pass through the water will burst with a slight explosion, and produce flashes of fire in the circumambient air; a circular dense white smoke rises horizontally like a ring, enlarging itself continually, and forming a sort of *corona* extremely beautiful if the air be perfectly tranquil.

* Another method of procuring this gas is, put to ten parts of water, one of phosphorus in small pieces: then two parts of granulated zinc; then add six parts of oil of vitriol of commerce. T. C.

The finest effect is produced when the flashes of gas succeed each other but slowly.

RATIONALE....We have noticed before that phosphorated hydrogen gas is nothing but hydrogen gas holding phosphorus in solution. When this gaseous fluid is presented to the atmospheric air or oxygen gas, the minutely-divided phosphorus rapidly attracts oxygen and kindles, setting fire at the same time to the hydrogen gas in contact with atmospheric air, and hence phosphoric acid and water are formed.

The circular crown of white smoke which rises after the explosion of the gas, originates from the coat of water which enveloped the bubble of the gas; this water, together with what is formed during the explosion, is suddenly converted into vapour, it unites to the phosphoric acid produced, and thus constitutes the circular crown of smoke which rises like a ring.

If a wide mouthed phial be filled with phosphorated hydrogen gas and left in that situation over mercury, the gas will take fire when suffered to escape into the air by inclining the phial.

REMARK....This last is a hazardous experiment: the phial is often burst to pieces; it is therefore necessary to surround it with a cloth, in order to avoid dangerous events. An elastic gum bottle may be used for this purpose with safety.*

EXPERIMENT II.

Accension of phosphorated hydrogen gas by means of oxygen gas.

Fill a receiver with oxygen gas, and convey into it a few bubbles of phosphorated hydrogen gas. At the instant of the union of the gases, a brilliant flash of fire takes place, accompanied with a report.

The rationale of this experiment is analogous to the former.

REMARK....Great caution is necessary in performing this experiment. The dilatation of the gases which takes place during the explosion is so great that the vessel is apt to be blown to pieces. Not more than a single small bubble of the phosphorated hydrogen gas should be con-

* Invert a tin case over the phial before you let out the gas. T. C.

veyed into the oxygen gas at once, except the receiver be made of very thick glass.

Experiment III.

Accension of phosphorated hydrogen gas, by means of oxygenized muriatic acid gas.

If fresh-prepared phosphorated hydrogen gas and oxygenized muriatic acid gas are mingled together over mercury, a considerable detonation takes place, accompanied with a lambent green flame and dense white vapour.

Rationale....All that happened in the last experiments takes place in this instance. The oxygenized muriatic acid is robbed of its oxygen, and becomes converted into simple muriatic acid gas; and water and phosphoric acid are produced. The evolved heat inflames the phosphorus which was dissolved in the gas.

Remark....For the success of this experiment it is essential that both gases are fresh prepared. The receiver in which the mixture is made should be very strong, in order to guard against accidents, and the gas introduced gradually by a bubble at a time.

Experiment IV.

Phosphorated hydrogen gas burns with a green light in nascent oxygenized muriatic acid gas, under the surface of water.

Put into an ale-glass, or Florence flask, one part of phosphuret of lime, broken into pieces of the size of a pea (*not in small fragments or in powder*) and add to it half a part of oxygenated muriate of potash. Fill the vessel with water, and bring carefully into contact with the materials at the bottom of the fluid three or four parts of concentrated sulphuric acid. This may be most conveniently done, by letting the acid fall through a long-necked funnel, reaching to the bottom of the vessel, or by causing it to pass down the sides of it. As soon as the decomposition of the water and that of the oxygenated muriate takes place, flashes of fire dart from the surface of the fluid, and the phosphuret illuminates the bottom of the vessel with a beautiful green light.

Experiment V.

A riband or piece of silk, impregnated with a solution of muriate of gold, may be gilt by the action of phosphorated hydrogen gas.

Take a silk riband, wet it thoroughly with a solution of muriate of gold, and expose it over mercury to the action of phosphorated hydrogen gas for a few days; the riband in this situation will become covered with gold. The gilding is so permanent that it will bear washing.

Rationale.. .The hydrogen of the phosphorated hydrogen gas unites to part of the oxyd of gold dissolved in the acid, and forms water. The phosphorus thus separated unites to another part of the oxygen, and produces phosphoric acid. The gold therefore on losing its oxygen totally becomes reduced to the metallic state, and attaches itself by virtue of a strong molecular attraction to the riband.

Remark....One part of the crystallized muriate of gold dissolved in eighteen parts of distilled water, seems to answer this purpose extremely well.

If the gilding be repeated a second, or even a third time, its lustre becomes extremely beautiful.*

Experiment VI.

Phosphorated hydrogen gas and sulphureous acid gas decompose each other.

Let phosphorated hydrogen gas and sulphureous acid gas, both obtained over mercury, be mingled together, the two gases will lose their elasticity; plates of yellow matter are deposited on the sides of the vessel, which take fire on hot iron, first in the manner of phosphorus, and afterwards with the characters of sulphur.

Rationale....It follows from this experiment that the hydrogen is the only substance which combines with the oxygen in these circumstances, since the gases lose their fluidity and deposit respectively the sulphur and phosphorus contained in them.

* Mrs. Fulhame invented this experiment. T. C.

Experiment VII.

Phosphorated hydrogen gas is decomposed by vivid light.

Though phosphorated hydrogen gas may be kept over mercury in the dark for any length of time unaltered, this is not the case if the gas be exposed to light. If a bottle filled with this gas be painted partly black, or surrounded with black paper, and then exposed to the light of the sun, the union of the phosphorus and hydrogen will be broken, and the phosphorus will be found crystallized at those parts through which the rays of light were suffered to pass, and the hydrogen gas will be left behind.

NITROUS GAS.

PART XXV.

SECT. I.

THE name of nitrous gas is given to an aeriform fluid, consisting of a certain quantity of nitrogen gas and oxygen: first described by Priestley, but in some measure known before to Hales.

PROPERTIES OF NITROUS GAS.

Nitrous gas is an elastic colourless fluid, having no sensible taste: it is neither acid nor alkaline; it is exceedingly hurtful to animals, producing instant suffocation whenever they attempt to breathe it. The greater number of combustible bodies refuse to burn in it. It is nevertheless capable of supporting the combustion of some of these bodies. Phosphorus burns in nitrous gas when introduced into it in a state of inflammation; pyrophorus takes fire in it spontaneously.

It is not decomposable by water; though 100 cubic inches of this fluid, when freed from air, absorb about 11.8 cubic inches of gas. This solution is void of taste; it does not redden blue vegetable colours; the gas is expelled again when the water is made to boil or suffered to freeze. It has no action on nitrogen gas even when assisted by heat. It is decomposed by several metals at high temperatures.

Its specific gravity, when perfectly pure, is to that of atmospheric air as 1.093 to 1.

Ardent spirit, saccharine matters, hydro-carbonates, sulphureous acid, and phosphorus, have no action on it. It is not sensibly changed by the action of light. Heat dilates it. It rapidly combines with oxygen gas at common temperatures, and converts it into nitrous acid. Atmospheric air produces the same effect, but with less intensity. It is absorbable by green sulphate, muriate, and nitrate of iron, and decomposable by alkaline, terrene, and metallic sulphurets, and other bodies that have a strong affinity for oxygen; but is not capable of combining with them chemically, so as to form saline compounds. From the greatest number of bodies which absorb it, it may be again expelled by the application of heat.

It communicates to flame a greenish colour before extinguishing it; when mixed with hydrogen gas it acquires the property of burning with a green flame. It is absorbable by nitric acid, and renders it fuming.

When exposed to the action of caloric in an ignited porcelain tube, it experiences no alteration; but when electric sparks are made to pass through it, it is decomposed and converted into nitrous acid and nitrogen gas. Phosphorus does not shine in it. It is composed of 56 parts of oxygen, and 44 nitrogen.

METHODS OF OBTAINING NITROUS GAS.

1. Put into a small proof or retort some copper wire, or pieces of the same metal, and pour on it nitric acid of commerce diluted with water; an effervescence takes place and nitrous gas will be produced. After having suffered the gas to escape for a few minutes on account of the atmospheric air contained in the retort, collect the gas in the water apparatus as usual. In order to obtain the gas in a pure state, it must then be shook for some time in contact with water.

RATIONALE....We have seen before that water was decomposed on bringing in contact with it a metal and an acid; but here the case is different; the water in this instance suffers no alteration, on the contrary, the acid undergoes a partial decomposition; the metal

robs the nitric acid of the greatest part of its oxygen, and becomes oxydated; the remainder of the acid having lost so much of its oxygen, becomes thereby so altered, that at the usual temperature it can exist no longer in the liquid state, but instantly expands, and assumes the form of gas; ceasing at the same time to act as an acid, and exhibiting different properties.

Instead of presenting copper to nitric acid, iron, zinc, mercury, or silver, may be made use of. The metals best suited for the production of nitrous gas are silver, mercury, and copper.

2. Nitrous gas may likewise be obtained by synthesis. This method of obtaining it we owe to Dr. Milner of Cambridge.

In the middle of an earthen tube about 20 inches long, and $\frac{3}{4}$ wide, open at both ends, put as much coarsely-powdered manganese as is sufficient nearly to fill it. Let this tube traverse the universal furnace. To one end of the tube lute a retort containing water strongly impregnated with ammonia, and to the other adapt a bent glass tube which passes into the pneumatic trough. Let a fire be kindled in the furnace, and when the manganese may be supposed to be red-hot apply a gentle heat to the retort, and drive over it the vapour of the ammonia; the consequence will be that nitrous gas will be delivered at one end of the tube, at the time that the ammonia enters the other end; and this effect does not take place without the presence of the alkali.

RATIONALE....Ammonia consists of hydrogen and nitrogen: its hydrogen combines with the oxygen which is given out by the ignited manganese, and forms water; its nitrogen unites at the same time to another portion of the oxygen, and constitutes the nitrous gas.

REMARK....There is a cause of deception in this experiment, against which the operator ought to be on his guard, lest he should conclude no nitrous gas is formed, when in reality there is a considerable quantity. The ammonia, notwithstanding every precaution, will frequently pass over undecomposed. If the receiver in the pneumatic trough is filled with water, great part of this will indeed be presently absorbed, but still some portion of it will mix with the nitrous gas formed in the process. Upon admitting the atmospheric

air, the nitrous gas will become decomposed, and the red nitrous fumes instantly unite with the alkali. The receiver is presently filled with white clouds of nitrate of ammonia; and in this manner a wrong conclusion may easily be drawn from the want of the orange colour of the nitrous fumes. A considerable quantity of nitrous gas may have been formed, and yet no orange colour appear, owing to this circumstance; and therefore it is easy to understand how a small quantity of nitrous gas may be most effectually disguised by the same cause.

Dr. Milner* also obtained nitrous gas, by passing ammoniacal gas over sulphate of iron deprived of its water of crystallization.†

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF NITROUS GAS.

EXPERIMENT I.

Nitrous gas decomposes atmospheric air.

It was mentioned before that nitrous gas greedily attracts oxygen of the atmospheric air. We shall demonstrate this fact, and show at the same time that during this union an acid is produced.

Pass up into a cylindrical glass vessel, over water, about one measure of nitrous gas and two of common air; the two fluids will speedily unite, red fumes will be produced, and the volume of the two combined gases will be diminished. A considerable degree of heat will be perceived, the water will rise in the cylinder and absorb the red vapours. When the two gases have been mixed in due proportion, nothing remains at last but the nitrogen gas of the atmospheric air. Usually 16 measures of common air are requisite to destroy completely $7\frac{1}{3}$ measures of nitrous gas, this however varies according to the purity of the airs.

RATIONALE....The nitrous gas in this experiment decomposes the atmospheric air; it takes the oxygen from the nitrogen gas, unites with it, and forms nitrous acid;

* Phil. Trans. LXXIX. p. 300.

† When this gas is kept in a phial well corked, with a little water in it, nitrate of ammonia is formed by decomposition of the water. T. C.

the nitrogen is therefore left behind; the heat which is generated is the caloric which kept the gases in solution, which now becomes liberated.

If instead of atmospheric air oxygen gas be substituted, this phenomenon will be still more striking. If a pint of pure oxygen gas be mixed with two of nitrous gas, the redness will be much greater, and the volume of the gases almost entirely disappear.

REMARK....Upon the property which nitrous gas has of absorbing the oxygen of the atmosphere, Priestley and Fontana founded the construction of their eudiometers already mentioned.

EXPERIMENT II.

Proofs that an acid is produced during the mixture of nitrous gas and atmospheric air or oxygen gas.

Paste a slip of litmus paper within a glass jar, near the bottom, and into the jar, filled with and inverted in water, pass as much nitrous gas, previously well washed, as will displace the fluid below the level of the paper; the blue colour of the paper will remain unaltered, but on sending up atmospheric air, or oxygen gas, it will immediately change its blue colour to red. A sure proof that an acid has been formed.

That it is nitrous acid which is produced by the union of nitrous gas, and oxygen gas may be evinced in the following

EXPERIMENT III.

Into a jar filled with and inverted over mercury put a small quantity of solution of pure potash, and afterwards measures of oxygen and nitrous gases separately and in proper proportion as long as an absorption takes place. On removing the solution from the jar and evaporating it in a glass basin, crystals of salt will be formed, which exhibit all the properties of nitrate of potash.

EXPERIMENT IV.

Nitrous gas is absorbed by nitric acid, to which it gives new characters.

Let nitrous gas pass as it is liberated from the materials

which afford it into a bottle containing colourless nitric acid; the acid will first become yellow, then green, next orange coloured, and at last dark olive coloured and fuming.

RATIONALE....The change of colour depends on the absorption of different quantities of nitrogen gas. Priestley found that 100 parts of nitric acid of a moderate strength absorbed in two days 90.29 of nitrous gas. He informs us that when about seven parts were absorbed, the acid assumed an orange colour; when eighteen parts were absorbed, a green colour; and that when the 90.29 were combined it became red and fuming.

REMARK....If the olive coloured acid be diluted with water, it becomes blue; the orange coloured when united with water becomes emerald green; and a large quantity of water renders either of them colourless.

EXPERIMENT V.

Nitrous gas which has been absorbed by nitric acid may be expelled again from this fluid.

This may be shown by gently heating the acid coloured in the before-going experiment till it becomes limpid. In this experiment light should be excluded.

RATIONALE....The nitrous gas absorbed by the acid has a greater affinity for caloric than the nitric acid has; this property therefore is here employed for disengaging the nitrous gas which rendered the acid fuming.

EXPERIMENT VI.

Nitrous gas tinges the flame of burning bodies green.

Fill a wide mouthed bottle with a mixture of one part of nitrous gas, and four of hydrogen gas; set fire to it with a lighted taper, and the mixture will burn with a green flame.

If a lighted taper be immersed in nitrous gas, it exhibits a green flame before the taper becomes extinguished.

Experiment VII.

Nitrous gas is unfit for maintaining the combustion of the greater number of burning bodies.

Fill a receiver with nitrous gas, and let down into it a burning taper; the taper will instantly be extinguished: the same thing will happen to ardent spirit, oils, &c. though burning with a vivid flame.

That nitrous gas however is capable of supporting the combustion of other bodies will be obvious from the following experiments:

Experiment VIII.

Accension of pyrophorus in nitrous gas.

Place some new made pyrophorus in a copper spoon, and introduce it into a receiver filled with nitrous gas; the pyrophorus will instantly take fire, and the volume of the gas will become diminished.

Rationale....The pyrophorus effects a real analysis of the gas, it subtracts its oxygen, and leaves its nitrogen behind: hence if the remaining air be examined it will be found that it renders lime or barytic water turbid, and that it undergoes no further diminution when mingled with oxygen gas; it is therefore a mixture of carbonic acid and nitrogen gas.

Experiment IX.

Nitrous gas maintains the combustion of phosphorus when introduced in a state of actual inflammation.

Though phosphorus may be fused and even sublimed in nitrous gas without producing the slightest luminous appearance, if the gas be perfectly pure; yet if a bit of phosphorus be placed in a copper ladle, then inflamed and introduced into the gas when in a state of actual inflammation, it burns with almost as much brilliancy as in oxygen gas.

RATIONALE....The rationale of this experiment proves that at the heat of ignition, phosphorus is capable of disturbing the equilibrium of the affinity subsisting between oxygen and nitrogen in nitrous gas, on which account it attracts the former from the nitrous gas, and leaves the latter behind.

EXPERIMENT X.

Nitrous gas inflames charcoal when introduced in a state of ignition.

If a piece of charcoal thoroughly ignited be introduced into nitrous gas there will also be a vivid inflammation; this experiment may likewise be performed by setting fire to the charcoal confined in nitrous gas by means of a burning lens.

RATIONALE....The charcoal at the temperature of ignition decompòses the nitrous gas by subtracting its oxygen; hence carbonic acid is formed, which may be evinced by admitting to the residuary gas a solution of barytes, strontia, or lime in water.

EXPERIMENT XI.

Nitrous gas is absorbed by green muriate, sulphate, and nitrate of iron.

A very concentrated solution of pure green muriate of iron (prepared by dissolving iron filings perfectly free from rust in muriatic acid, evaporating the solution briskly, and preserving it from the contact of atmospheric air) is extremely well calculated to ascertain the quantity of nitrogen gas contained in a given quantity of nitrous gas in an easy manner.

To prove the absorption of nitrous gas by this means, it is only necessary to agitate in a graduated tube a quantity of the gas in contact with the solution; the green solution of iron will soon assume a brown colour, the gas will be diminished, and the solution ascend into the tube.

A solution of pure green sulphate of iron (prepared by dissolving clean iron filings in sulphuric acid, and then

agitating the solution in contact with sulphurated hydrogen gas) answers the same purpose. Pale green nitrate of iron may likewise be used with advantage.

RATIONALE....The absorption of the nitrous gas, by means of these solutions, takes place without any decomposition of it at common temperatures. It depends merely on an equilibrium of affinity produced by the following simple attractions.

1. That of green oxyd of iron for the oxygen of nitrous gas and water.

2. That of the hydrogen of the water for the nitrogen of the nitrous gas; and,

3. That of the principles of the sulphuric acid for nitrogen and hydrogen.

REMARK....That this is the true cause of the absorption professor Davy has sufficiently proved in his Researches, p. 176. Vauquelin and Humbolt have been mistaken with regard to its nature;* the products they obtained must have arisen from the exposure of their impregnated solutions to the atmosphere.

The absorption of nitrous gas by means of these solutions of iron is proportionable to the degree of the concentration of the solution.

Seventy-five cubic inches of concentrated solution of muriate of iron absorb about 18 of nitrous gas. Sulphate of iron absorbs only one half of this quantity; the gas absorbed may be expelled again by heat.

Nitrous gas (according to Davy) is also absorbed by means of white prussiate of iron, in contact with water; by sulphate of tin; sulphate and muriate of zinc at the *minimum* of oxydation; and probably by many other metallic solutions hitherto not tried.

In fact, whenever the metals capable of decomposing water exists in solution at their *minimum* of oxydation, the affinities exerted by them on nitrous gas and water will be such as to produce combinations; the powers of metallic solutions to combine with nitrous gas at common temperatures, as well as to decompose it at higher temperatures, Davy supposes to be probably in the ratio of the affinity of the metallic oxyds they contain for oxygen.

* Annales de Chimie, tom. 88, p. 187.

Experiment XII.

Decomposition of nitrous gas by nascent hydrogen gas.

When nitrous gas is exposed to wetted iron filings, a diminution of its volume slowly takes place; the iron becomes oxydated, and ammonia is formed.

For performing this experiment, wetted iron filings may be exposed on a shallow dish or plate supported by a stand to the action of the gas contained in a broad receiver; the vessel containing the iron filings may next be removed by withdrawing it through the water, and the remaining gas may be made the subject of experiment.

This decomposition of nitrous gas is more quickly effected by putting plates of iron into a solution of nitrate of copper.

Rationale....The water in contact with the iron is decomposed by virtue of the affinity subsisting between its oxygen and the iron. Its hydrogen, with a portion of oxygen, at the same time attracts the nitrogen of the nitrous gas, and produces water, ammonia, and nitrous oxyd.

Remark....That the iron is not oxydated in this process at the expence of the oxygen of the nitrous gas becomes obvious, when we consider that water is essentially necessary to produce the decomposition; for dry iron filings effect no change whatever in nitrous gas at the usual temperatures.

Alkaline sulphurets moistened with water, put into a vessel filled with nitrous gas, decompose it in a short time; the remaining gas is no longer reddened by the contact of air, the greatest part is nitrous oxyd.

Experiment XIII.

Nitrous gas is decomposed by exposure to zinc and water.

When nitrous gas is exposed to a large surface of zinc in contact with water, it will be slowly converted into nitrous oxyd; at the same time that ammonia is generated and white oxyd of zinc is formed, if the process is suffered to go on for a considerable time.

RATIONALE....These phenomena depend, like the former, upon the decomposition of water by the affinities of part of the oxygen and nitrous gas, for its hydrogen to form ammonia and water.

REMARK....Zinc placed in contact with water, and confined, by mercury, decomposes it, as Davy observed, at common temperatures. But zinc, when perfectly dry, does not in the slightest degree act upon nitrous gas. Van Marum remarked that tin, lead, iron, and mercury, were all oxydated by taking the electric spark in contact with nitrous gas. Davy, who has made the greatest number of experiments concerning the nature of nitrous gas, considers the analysis of it by charcoal as affording *data* best calculated for determining the respective quantities of nitrogen and oxygen in a given bulk of nitrous gas, and correcting it by mean calculations derived from the decomposition of nitrous gas by pyrophorus and hydrogen, and its conversion into nitrous oxyd, concluded that 100 grains of nitrous gas are composed of 55.95 of oxygen and 44.05 of nitrogen gas; or taking away decimals of 56. oxygen and 44. nitrogen gas. This estimation agrees very well with the mean proportions of Priestley's experiments. But as Priestley never ascertained the absolute purity of the gas he made use of, and probably employed different kinds, in different experiments, it is impossible to fix on any one from which accurate conclusions can be drawn.

Lavoisier's estimation of the respective quantities of oxygen and nitrogen gas entering into the composition of nitrous gas has been generally adopted. He supposed 64 parts of nitrous gas to be composed of 43½ of oxygen and 20½ of nitrogen gas. The difference between this and Davy's account is very great indeed; but Davy* has pointed out many sources of error in the experiments of this great man concerning the decomposition of nitrate of potash by charcoal, which were fundamental to his account of the composition of this gas.†

* Researches chemical and philosophical, 1800, Div. 1.

† Davy's proportions are by weight 56 oxygen 44 nitrogen. From the experiments and deductions of Thenard and Dalton

Atmospheric air by measure consists of 20 parts oxygen 80 nitrogen.

Nitrous oxyd	33,33	66,66
Nitrous gas	50	50
Nitrous acid vapour	62,5	37,5
Nitric acid	66,66	33,33

T.C.

GASEOUS OXYD OF NITROGEN; OR NITROUS OXYD.

PART XXVI.

THE combination of nitrogen and oxygen, which we considered before under the name of nitrous gas, does not constitute the first degree of oxygenation of nitrogen; there is another degree below this. This combination was formerly called dephlogisticated nitrous gas, but now gaseous oxyd of nitrogen, or nitrous oxyd. It was first discovered by Priestley. Its nature and properties have since been investigated (though not very accurately) by a society of Dutch chemists.

Professor Davy has examined with uncommon accuracy the formation and properties of all the substances concerned in its production. He has detected the sources of error in the experiments of Priestley and the Dutch chemists, and to him we are indebted for a thorough knowledge of this gas. We shall therefore exhibit the philosophy of this gaseous fluid as we find it in his researches concerning the nitrous oxyd.

SECT. I.

PROPERTIES OF GASEOUS OXYD OF NITROGEN.

GASEOUS oxyd of nitrogen exists in the form of permanent gas. A candle burns with a brilliant flame and crackling noise in it; before its extinction the white inner flame becomes surrounded with a blue one.

Phosphorus introduced into it, in a state of actual inflammation, burns with increased splendour, as in oxygen gas. Sulphur introduced into it when burning with a feeble blue flame is instantly extinguished; but when in a state of *vivid inflammation*, it burns with a rose-coloured flame. Ignited charcoal burns in it more brilliantly than in atmospheric air. Iron wire, with a small piece of wood affixed to it when inflamed, and introduced into a vessel filled with this gas, burns vehemently, and throws out bright scintillating sparks. No combustible body however burns in it unless it be previously brought to a state of vivid inflammation. Hence sulphur may be melted, and even sublimed in it; phosphorus may be liquefied in it without undergoing combustion. Nitrous oxyd is pretty rapidly absorbed by water that has been boiled; a quantity of gas equal to rather more than half the bulk of the water may be thus made to disappear; the water acquires a sweetish taste, but its other properties do not differ perceptibly from common water. The whole of the gas may be expelled again by heat. It does not change blue vegetable colours. It has a distinctly sweet taste, and a faint but agreeable odour. It undergoes no diminution when mingled with oxygen or nitrous gas. Most of the liquid inflammable bodies, such as ether, alcohol, volatile and fat oils, absorb it rapidly and in great quantity. Acids exert but little action on it. The affinity of the neutro-saline solutions for gaseous oxyd of nitrogen is very feeble. Green muriate and green sulphate of iron, whether holding nitrous gas in solution or not, do not act upon it. None of the gases, when mingled with it, suffer any perceptible change at common temperatures; the muriatic and sulphureous acid gases excepted, which undergo a slight expansion. Alkalies freed from carbonic acid exposed in the dry or solid form have no action upon it; they may however be made to combine with it in the nascent state, and then constitute *saline compounds* of a peculiar nature. These combinations deflagrate when heated with charcoal, and are decomposed by acids; the gaseous oxyd of nitrogen being disengaged. It undergoes no change whatever from the simple effect of light. The action of the electric spark for a long while continued, converts it into a gas analogous to atmospheric air and nitrous acid; the same is the case when it is made to pass

through an ignited earthen tube. It explodes with hydrogen in a variety of proportions at very high temperatures; for instance, when electric sparks are made to pass through the mixture. Sulphurated hydrogen, heavy and light carbonated hydrogen gases, and gaseous oxyd of carbon, likewise burn with it when a red heat is applied. 100 parts by weight of nitrous oxyd contain 36.7 of oxygen and 63.3 of nitrogen; 100 cubic inches weigh 50 grains at 55° temperature and 30 atmospheric pressure. Animals when wholly confined in gaseous oxyd of nitrogen give no signs of uneasiness for some moments, but they soon become restless and die. When gaseous oxyd of nitrogen is mingled with atmospheric air, and then received into the lungs, it generates highly pleasurable sensations; the effects it produces on the animal system are eminently distinguished from every other chemical agent. It excites every fibre to action, and rouses the faculties of the mind, inducing a state of great exhilaration, an irresistible propensity to laughter, a rapid flow of vivid ideas, and unusual vigour and fitness for muscular exertions, in some respects resembling those attendant on the pleasantest period of intoxication, without any subsequent languor, depression of nervous energy, or disagreeable feelings; but more generally followed by vigour, and a pleasurable disposition to exertion, which gradually subsides.

Such are the properties which characterize the nitrous oxyd.

The Dutch chemists and some French and German philosophers assert* that it cannot be respired; that burning phosphorus, sulphur, and charcoal, are extinguished in it, &c. It is probable they did not examine it in a state of purity, for it is otherwise difficult to account for these and many other erroneous opinions.

METHODS OF OBTAINING GASEOUS OXYD OF NITROGEN.

Gaseous oxyd of nitrogen is produced when substances having a strong affinity with oxygen are brought into

* Gren's Principles of Chemistry, 1800. Scherer's Introduction to the Knowledge of Gaseous Bodies, 1801.

contact with nitric acid, or with nitrous gas. It may therefore be obtained by various processes, in which nitrous gas or nitric acid is decomposed by substances capable of attracting the greater part of their oxygen. The most commodious and expeditious, as well as the cheapest mode of obtaining it, is by decomposing nitrate of ammonia, *at a certain temperature*, in the following manner.

1. Introduce into a glass retort some nitrate of ammonia, and apply the heat of an Argand's lamp; the salt will soon liquefy, and when it begins to boil, gas will be evolved. Increase the heat gradually till the body and neck of the retort become filled with a semi-transparent milky-white vapour. In this state the temperature of the fused nitrate is between 340° and 480°. After the decomposition has proceeded for a few minutes, so that the gas evolved quickly enlarges the flame of a taper held near the orifice of the retort, it may be collected over water, care being taken during the whole process never to suffer the temperature of the fused nitrate to rise above 500° Fahr. which may be easily judged of, from the density of the vapours in the retort, and from the quiet ebullition of the fused nitrate; for if the heat be increased beyond this point the vapours in the retort acquire a reddish and more transparent appearance; and the fused nitrate begins to rise, and occupy twice the bulk it did before. The nitrous oxyd after its generation is allowed to stand over water for at least six hours, and is then fit for respiration or other experiments. (*See Appendix No.* 26.)

RATIONALE....Nitrate of ammonia consists of nitric acid and ammonia; nitric acid is composed of nitrous gas and oxygen; and ammonia consists of hydrogen and nitrogen. At a temperature of about 480° the attractions of hydrogen for nitrogen in ammonia, and that of nitrous gas for oxygen in nitric acid, are *diminished*; while, on the contrary, the attractions of the hydrogen of ammonia for the oxygen of the nitric acid, and that of the remaining nitrogen of the ammonia for the nitrous gas of the nitric acid, are *increased*: hence all the former affinities are broken, and new ones produced, namely; the hydrogen of the ammonia attracts the oxygen of the nitric acid, the result of which is *water*; the nitrogen of the ammonia combines with the liberated nitrous gas, and forms *nitrous*

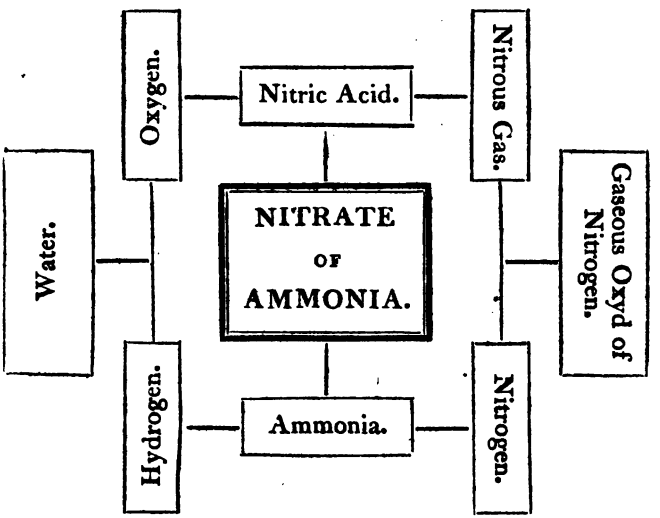
oxyd. The water and nitrous oxyd produced probably exist in binary combination in the aeriform state at the temperature of the decomposition.

Such is the philosophy of the production of gaseous oxyd of nitrogen, by decomposing nitrate of ammonia at that temperature, given by Davy.

To illustrate this complicated play of affinity more fully, the following sketch may not be deemed superfluous.

DIAGRAM,

EXHIBITING THE PRODUCTION OF GASEOUS OXYD OF NITROGEN, BY DECOMPOSING NITRATE OF AMMONIA AT 480° FAHR.



REMARK....Professor Davy has likewise pointed out, that when the heat employed for decomposing nitrate of ammonia is raised above the before-stated temperature, another play of affinities takes place; the attractions of nitrogen and hydrogen for each other, and of oxygen for nitrous gas, are still more diminished, whilst that of nitrogen for nitrous gas is totally destroyed, and that of hydro-

gen for oxygen increased to a greater extent. A new attraction likewise takes place, namely, that of nitrous gas for nitric acid to form *nitrous vapour*,* and a new arrangement of principles is rapidly produced: the nitrogen of the ammonia having no affinity for any of the single principles at this temperature, enters into no binary compound; the oxygen of the nitric acid forms water with the hydrogen, and the nitrous gas combines with the nitric acid to form *nitrous vapour*.

All these substances most probably exist in combination at the temperature of their production; and at a lower temperature assume the form of *nitrous acid*, *nitrous gas*, *nitrogen*, and *water*; and hence we see the necessity of not heating the nitrate of ammonia above the beforestated temperature.

On account of the rapid absorption of gaseous oxyd of nitrogen by water, it is economical to preserve the fluid which has been used to confine this gas, and to make use of it for collecting other quantities of it. In order to hasten its production, the nitrate of ammonia may be previously freed from its water of crystallization by gently fusing it in a glass of Wedgwood's basin for a few minutes, and then keeping it for use in a well-stopped bottle.

2. Nitrous oxyd may likewise be obtained by exposing common nitrous gas to alkaline sulphites, particularly to sulphite of potash containing its full quantity of water of crystallization. The nitrous oxyd produced from nitrous gas by sulphite of potash, has all the properties of that generated from the decomposition of nitrate of ammonia.

RATIONALE....The conversion of nitrous gas into nitrous oxyd by these bodies, depends on the abstraction of a portion of its oxygen by the greater affinity of the sulphite presented to it. The nitrogen and remaining oxygen assume a more condensed state of existence, and constitute nitrous oxyd.

3. Nitrous oxyd may also be obtained by mingling together nitrous gas and sulphurated hydrogen gas. The volume of gases in this case is diminished, sulphur deposited, ammonia, water, and nitrous oxyd are formed.

RATIONALE....The change of principles which takes place in this experiment depends upon the combination of the hydrogen of the sulphurated hydrogen gas with dif-

* Hence the reddish vapour in the retort, stated before, p. 324.

ferent portions of the oxygen and nitrogen of the nitrous gas, to form water and ammonia, and to deposit sulphur. The remaining oxygen and nitrogen being left in due proportion to constitute nitrous oxyd.

Remark....This singular exertion of attractions by a simple body appears highly improbable, *a priori;* but the formation of ammonia, and the non-oxygenation of the sulphur, elucidate the fact. In performing this experiment, care should be taken that the gases should be rendered as dry as possible; for the presence of water considerably retards the decomposition.

4. Nitrous oxyd may also be produced by presenting alkaline sulphurets to nitrous gas. Davy observed that a solution of sulphuret of strontia or barytes answers this purpose best.

Rationale....This decomposition of nitrous gas is not solely produced by the abstraction of oxygen from the nitrous gas to form sulphuric acid. It depends equally on the decomposition of the sulphurated hydrogen dissolved in the solution or liberated from it. In this process sulphur is deposited, and sulphuric acid formed.

5. Nitrous oxyd is obtained in many circumstances similar to those in which nitrous gas is produced. Dr. Priestley found that nitrous oxyd was evolved, together with nitrous gas, during the solution of iron, tin, and zinc, in nitric acid.

Rationale....It is difficult to ascertain the exact rationale of these processes, for very complicated agencies of affinities take place. Either the nascent hydrogen arising from the decomposition of the water by the metallic substance may combine with portions of the oxygen and nitrogen of the nitrous gas; and thus by forming water and ammonia, convert it into nitrous oxyd; or the metallic substance may attract at the same time oxygen from the water and nitrous gas, whilst the nascent hydrogen of the water seizes upon a portion of the nitrogen of the nitrous gas to form ammonia. The analogy between this process and the decomposition of nitrous gas by sulphurated hydrogen, renders the first opinion most probable.

Such are the principal methods of obtaining nitrous oxyd. There are no reasons, Davy thinks, for supposing that nitrous oxyd is formed in any of the processes of nature; and the nice equilibrium of affinity by which it is

constituted forbids us to hope for the power of composing it from its simple principles. We must be content to produce it artificially.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF GASEOUS OXYD OF NITROGEN.

Experiment I.

Gaseous oxyd of nitrogen is rapidly absorbed by water.

FILL a glass cylinder or graduated tube with water previously boiled, and invert it in a basin of the same fluid. Having done this, send up into it a quantity of nitrous oxyd, and mark the level of the water in the cylinder. Then agitate it for a few minutes in the water, and the bulk of the gas will be seen considerably diminishing. Water may thus be made to absorb about one half of its own bulk of gaseous oxyd of nitrogen.

On boiling the water, the gas which was absorbed will be liberated, possessing all its former properties.

If nitrous oxyd be repeatedly exposed to water, the residual gas will be the common air previously contained in the water, and from which it can in no case be perfectly freed by ebullition; this air becomes separated on account of the greater affinity of water for nitrous oxyd.

The quantity of common air thus produced generally amounts to about $\frac{1}{76}$ part of the volume of water.

The absorption of nitrous oxyd by the inflammable fluids enumerated before may be evinced in a similar manner. (*See Appendix No.* 27.)

Experiment II.

Combustible bodies do not burn in gaseous oxyd of nitrogen, except when in a state of actual inflammation.

Fill a jar over mercury with gaseous oxyd of nitrogen, and keep it over that fluid; introduce into it a small piece

of sulphur, camphor, or phosphorus, and touch these substances with a bent wire heated to a *dull redness*. The sulphur, camphor, or phosphorus, will melt, and continuingt he heat may even be made to sublime in the gas, but no accension will take place.

But that the gas is capable of maintaining the combustion of inflammable substances becomes evident from the following facts:

Experiment III.

Combustion of the taper in gaseous oxyd of nitrogen.

Immerse a lighted taper into a jar filled with nitrous oxyd. The flame of the taper will become instantly larger; it will first burn with a brilliant white flame, and sparkle as in oxygen gas. As the combustion goes on, the lustre of the flame diminishes; it gradually lengthens, and becomes surrounded with a pale blue cone of light, from the apex of which much unburnt charcoal is thrown off in the form of smoke. The flame continues double to the end of the process.

Experiment IV.

Combustion of phosphorus in gaseous oxyd of nitrogen.

Put a piece of phosphorus of the size of a pea into a copper ladle, set fire to the phosphorus with a match, and quickly introduce it into a jar filled with the gas. The phosphorus will continue to burn with a splendour nearly equal to that in oxygen gas.

The accension of phosphorus may likewise be evinced in the following manner.

Experiment V.

Fill a strong glass cylinder over mercury, one-eighth full of gaseous oxyd of nitrogen; send up into it a few

grains of phosphorus, heat a bent iron wire *white-hot*, and introduce it quickly through the mercury to touch the phosphorus, which thus will take fire instantly with a considerable detonation.

REMARK....This experiment requires caution: the cylinder in which the phosphorus is inflamed should be very strong. The gaseous oxyd employed should not exceed one-eighth of the capacity of the jar. The wire for the inflammation ought to be very well curved, so as to be expeditiously introduced into the jar, and capable of being quickly withdrawn. We have witnessed several accidents where the detonating jar burst during this experiment.

Another very successful method is as follows.

EXPERIMENT VI.

Let the jar containing the gaseous oxyd of nitrogen be placed over mercury; introduce the phosphorus in a small tube containing oxygen gas, so balanced as to swim on the surface of the mercury without communicating with the gaseous oxyd. The phosphorus is then fired in the oxygen gas with an ignited iron wire; by which, at the moment of combustion, the tube containing it must be raised into the gaseous oxyd, and thus the combustion continues.

EXPERIMENT VII.

Sulphur burning with a feeble blue flame becomes instantly extinguished in gaseous oxyd of nitrogen.

Put a piece of sulphur into a copper ladle, set fire to it by means of a candle, and when it begins to burn with a blue feeble flame, introduce it into a jar filled with gaseous oxyd of nitrogen. The sulphur will be extinguished the instant it is plunged into the gas.

But that sulphur may be made to burn in it becomes obvious from the following

EXPERIMENT VIII.

Sulphur, in a state of vivid inflammation, burns with a rose-coloured flame in gazeous oxyd of nitrogen.

Dip a slip of copper into melted sulphur; when cold set fire to it, and when in an actual state of combustion

introduce it into a jar filled with the gas, it will continue burning with a beautiful flame very much enlarged and of a vivid rose-colour.

This experiment may be more accurately performed in the same manner as the inflammation of phosphorus; namely, by introducing it into the small vessel filled with oxygen gas, and igniting it by means of the heated wire.

Experiment IX.

Detonation of gaseous oxyd of nitrogen with carbonated hydrogen gas.

Nitrous oxyd and carbonated hydrogen gas possess no action on each other except at high temperatures. But when mingled together in certain proportions and exposed to the electric spark, a new arrangement of their principles takes place. This may be proved in the following manner.

Mingle together in a detonating tube 35 parts of gaseous oxyd of nitrogen, and 15 of carbonated hydrogen gas. On passing the electric spark through it, the inflammation will be very vivid, and the light produced, bright red. After the explosion, the space occupied by the gases will be about 60.

When 22 parts of nitrous oxyd and 20 of hydro-carbonate are exploded, the residue fills a space equal to 45.

If strontia water be brought into contact with the gas after the detonation, a white precipitate is instantly formed and a diminution takes place. On presenting nitrous gas to this residue, the gas again becomes diminished.

Rationale....Reasoning from analogy, there can be little doubt but that when carbonated hydrogen gas is inflamed with excess of gaseous oxyd of nitrogen, it will be only partially decomposed or converted into nitrogen, nitrous acid, and atmospheric air.

Experiment X.

Gaseous oxyd of nitrogen and phosphorated hydrogen gas detonate likewise.

Posphorated hydrogen gas, and gaseous oxyd of nitrogen, exert no action upon each other at common tempera-

tures; but that they may be made to act upon each other at a very high temperature the following experiments will prove.

1. Mix ten grain measures of phosphorated hydrogen gas and 52 of gaseous oxyd of nitrogen in a graduated detonating tube, and pass the electric spark through it. A very vivid inflammation will take place, and the tube will be filled with white vapour. The volume of the gas left behind will fill a space nearly equal to 60. On agitating this fluid in contact with water no absorption will take place. On admitting nitrous gas a diminution ensues.

RATIONALE....It appears from this experiment that when a small quantity of phosphorated hydrogen gas is inflamed with gaseous oxyd of nitrogen, both the phosphorus and hydrogen are consumed; whilst the superabundant gaseous oxyd is converted into nitrous acid and atmospheric air by the ignition; or a certain quantity is partially decomposed into atmospheric air by the combination of a portion of its oxygen with the combustible gas.

2. Twenty-five parts of gaseous oxyd of nitrogen, mingled with 10 of phosphorated hydrogen gas, may likewise be inflamed. After the detonation, white dense vapours become visible, and the gas left occupies a space equal to 25. The residuary gas is not absorbable by water: on admitting a solution of green sulphate of iron, or prussiate of potash, no blue or green precipitate is produced; but if 25 parts of nitrous gas are mingled with it, the result will be 50.

RATIONALE....From this experiment we learn that when phosphorated hydrogen gas and gaseous oxyd are to each other as 25 to 10, they both disappear, whilst nitrogen is evolved, and water and phosphoric acid produced. Reasoning concerning the composition of gaseous oxyd of nitrogen from this result, we should conclude that it was composed of about 38 oxygen and 62 nitrogen.

3. Ten grain measures of gaseous oxyd, mingled with 20 of phosphorated hydrogen gas, cannot be inflamed.

4. Twenty-five of gaseous oxyd of nitrogen with 20 of phosphorated hydrogen gas inflame readily. The gas

after detonation is likewise opaque, and fills a space equal to about 45. The residue is not miscible with water; no white fumes are produced by admitting oxygen gas.

RATIONALE....Here we are taught that the affinity of phosphorus for the oxygen of gaseous oxyd of nitrogen is stronger than that of hydrogen at the temperature of ignition; so that when phosphorated hydrogen gas is mingled with a quantity of gaseous oxyd of nitrogen, not containing sufficient oxygen to burn both its constituent parts, the phosphorus only is consumed, and the hydrogen is liberated.

EXPERIMENT XI.

Combustion of charcoal in gaseous oxyd of nitrogen.

This experiment is best performed by introducing a small piece of charcoal into a jar filled with nitrous oxyd, confined by mercury, and then applying the focus of a burning lens. The charcoal will thus take fire, and burn vividly.

It may likewise be performed by fixing a piece of well-burnt charcoal to a copper wire, igniting the charcoal completely, and introducing it into the gas.

EXPERIMENT XII.

Combustion of iron in gaseous oxyd of nitrogen.

The experiment may be performed in a manner similar to the combustion of iron in oxygen gas, or more accurately, by setting fire to the touch-wood affixed to the wire by means of a burning glass.

EXPERIMENT XIII.

Combustion of zinc in gaseous oxyd of nitrogen.

Take shavings of zinc, form them into a ball, in the middle of which a few grains of phosphorus must be included affix the ball of zinc shavings to a copper wire, set fire to

the phosphorus, and introduce it into a receiver filled with the gas. The zinc will thus be made to burn with a beautiful white flame, surrounded by a green one, and dense white vapours of oxyd of zinc will fill the receiver.

Experiment XIV.

Accension of pyrophorus in gaseous oxyd of nitrogen.

Pyrophorus, which readily inflames in nitrous gas and in atmospheric air at a low temperature, requires for its combustion in nitrous oxyd a much greater degree of heat. It will not burn in it even at 212°. In order to inflame pyrophorus in gaseous oxyd of nitrogen over mercury, the wire must be strongly heated, but not ignited. The pyrophorus then takes fire, and burns with a splendid white light, greatly resembling that produced in oxygen gas.

INFERENCES.

From the preceding experiments it becomes evident that the inflammable bodies in general require for their combustion in gaseous oxyd of nitrogen much higher temperatures than those in which they burn in oxygen gas or atmospheric air. When intensely heated, they decompose it with the production of much heat and light, and become oxygenized. During the combustion of solid or fluid bodies producing flame in it, nitric acid is generated, and that probably from a new arrangement of principles analogous to those stated before. Likewise, when gaseous oxyd of nitrogen in excess is decomposed by inflammable gases, nitrous acid, and sometimes a gas analogous to common air, is produced, doubtless from the same cause.

Pyrophorus is the only body that inflames in gaseous oxyd of nitrogen below the temperature of ignition.

Phosphorus burns in it with a blue flame, probably forming with it only phosphorous acid a little above a dull red heat; but when heated more intensely, phosphoric acid is produced.

Charcoal, sulphur, iron, and the compound inflammable bodies, decompose this gas only at temperatures equal to or above that of ignition, probably each at a different temperature.

The double flame produced during the combustion of charcoal depends on the production of nitrous acid formed during the process; for it may be produced by plunging the taper into common air containing nitrous acid vapour, or in a mixture of gaseous oxyd of nitrogen and nitrogen gas, through which nitrous acid has been diffused. It is never perceived in the combustion till much nitrous acid is formed.

If a taper be suffered to burn in a mixture of equal parts of gaseous oxyd of nitrogen and nitrogen gas, it burns at first with a flame nearly the same as that of a candle in common air, whitish yellow. Before its extinction the interior white flame and exterior blue one are perceived.

Nitrous oxyd is therefore a gas unalterable in its constitution at temperatures below ignition. It is composed of oxygen and nitrogen, existing most probably in the most intimate union which those substances are capable of assuming. For it is unalterable by those bodies which are capable of attracting oxygen from nitrous gas and nitrous acid at common temperatures. The properties of nitrous oxyd approach to those of acids. (*See Appendix No.* 28.)

AMMONIA,

OR

AMMONIACAL GAS.

PART XXVII.

SECT. I.

THIS gas was first discovered by Dr. Priestley. It is composed of hydrogen and nitrogen, rendered gaseous by the addition of caloric.

PROPERTIES OF AMMONIA.

Ammoniacal gas has a strong and very pungent odour. It extinguishes flame, yet it increases the magnitude of the flame of a taper before extinction, producing a pale yellow colour round its edge. Animals cannot breathe it without death ensuing. It is lighter than atmospheric air, in the proportion of three to five. It tinges yellow vegetable colours brown, and blue ones green. It is rapidly absorbed by cold water; by ardent spirit, essential oils, ether, charcoal, sponge, bits of linen cloth, and all porous bodies.

When a piece of ice is brought in contact with this gas, it melts and absorbs the gas, while at the same time its temperature is diminished. It has no effect upon oxygen gas while cold; but when made to pass with it through an ignited tube, it detonates, and becomes decomposed. The same is the case with common air. It is also decomposed by phosphorus at high temperatures.

It does not explode when mixed with hydrogen gas. Nitrogen gas has no effect upon it. Atmospheric air does not combine with it at common temperatures, but only mixes with and dilutes it. When made to pass through ignited charcoal, it forms with it a substance called prussic acid. If brought into contact with acid gases, both gases lose their gaseous form and become concrete. It has no sensible action on earths, or on the *salino-terrene* substances. It combines readily with acids, and unites to sulphur when both are in a state of vapour. It reduces oxyds of metals to their metallic state, and is decomposed by them. It is also decomposed by electrization and by oxygenized muriatic acid gas, &c. When exposed to the temperature of—46° it crystallizes, and when suddenly cooled down to—68° it assumes a gelatinous appearance, and has scarcely any odour.*

METHODS OF OBTAINING AMMONIA.

1. Mix together equal quantities of muriate of ammonia and lime, separately powdered; introduce them into a gas-bottle or retort, apply the heat of a lamp, and receive the gas over mercury.

RATIONALE....Muriate of ammonia consists of muriatic acid and ammonia; on adding lime to it a decomposition takes place, the muriatic acid quits the ammonia and unites to the lime, in order to form muriate of lime, which remains in the retort, and the ammonia flies off in the state of gas.

REMARK....In order to obtain the gas in a state of purity it is essentially necessary that a considerable quantity of the gas first disengaged be suffered to escape, on account of the common air contained in the distilling vessel and in the interstices of the ingredients.

2. Ammonia may likewise be obtained by heating the liquid ammonia of the shops (water of pure ammonia, *Pharm. Lond.*) in a retort placed in communication with the mercurial pneumatic trough.

* Fourcroy and Vauquelin, Ann. de Chim. XXIX. p. 289.

RATIONALE.....The ammonia contained in this liquid combines with caloric, assumes the form of ammoniacal gas, and parts with the water to which it was united.

REMARK.....The temperature of the fluid must not be carried so high as to cause the water to be converted into vapour, or, if this cannot be well avoided, a small vessel should be interposed between the retort and the receiver; which, when kept cool, may serve to condense the aqueous vapour which is formed, and cause the ammoniacal gas to pass in a very pure and dry state.

Ammonia is likewise produced during the spontaneous decomposition of animal and vegetable substances; in these cases it did not pre-exist in them ready formed, but is generated by the union of the hydrogen and nitrogen contained in them.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF AMMONIA.

EXPERIMENT I.

Ammonia is absorbed by water, ardent spirit, &c.

INTRODUCE into a jar filled with ammonia standing over mercury a little water, ardent spirit, or a piece of moistened sponge, paper, &c. In whichever manner the experiment is made there will be an absorption; the gas becomes absorbed, and the mercury rises in the jar so as to fill it entirely, provided the gas be sufficiently pure.

If water be presented to this gas in the state of ice, it melts rapidly.

REMARK.....Water which has absorbed the gas acquires its peculiar odour, and constitutes what is called liquid ammonia, or, more properly, solution of ammonia in water. From this fluid the gas may be again liberated by heat.

EXPERIMENT II.

Ammonia extinguishes light, but increases the magnitude of the flame before its extinction.

A burning taper dipt several times successively into a

bottle filled with ammonia is extinguished every time, but before its extinction the flame is enlarged by the addition of another one of a pale yellow colour, and at length this light flame will extend from the top of the vessel to the bottom. If the lighted taper be only presented to the mouth of a vessel filled with ammonia, the yellowish flame will rise considerably higher than that of the taper.

Experiment III.

Ammonia is lighter than atmospheric air.

Let a jar filled with ammonia be placed with its mouth upwards, and left in that situation for a few minutes; it will be found to have exchanged its contents for common air, which, being heavier, descends and displaces the gas.

Experiment IV.

Ammonia is heavier than hydrogen gas.

Put a quantity of hydrogen gas into a long tube; add to it half the quantity of ammonia, and to this a like quantity of muriatic acid gas. The two latter gases will combine and form a white cloud (muriate of ammonia) but the cloud will not rise within the space occupied by the hydrogen gas; consequently the latter had kept its place below the other without mixing with it.

That the ammonia is lighter than the muriatic acid gas is shown from the formation of the white cloud on their mixture; for it begins at the bottom, and gradually reaches the top when the muriatic acid gas is last added; but when the ammonia is presented to the muriatic acid gas, the whole becomes cloudy immediately.

Experiment V.

Ammonia tinges yellow vegetable colours brown, and blue ones green.

This may be shown by pasting a piece of paper coloured yellow with turmeric, or blue with cabbage juice, into the

top of a receiver, and exposing it to the action of the gas. The first will soon become brown, and the latter green.

The same effect may be produced by holding the papers over a bottle filled with water impregnated with ammonia.

Experiment VI.

Carbonic acid gas and ammonia readily unite and form carbonate of ammonia.

Fill a vessel with carbonic acid gas over mercury, and add ammonia; a white vapour will instantly be formed, heat becomes evolved, the gases disappear, and carbonate of ammonia crystallizes on the inside of the vessel.

Experiment VII.

Ammonia becomes decomposed by oxygenized muriatic acid gas at common temperatures.

Mix in a receiver over mercury two parts of oxygenized muriatic acid gas with one part, by measure, of ammonia. When these two bodies come in contact, a brisk detonation is produced, accompanied with a yellowish light; the two gases decrease in volume, and there is formed a portion of solid matter (muriate of ammonia) which adheres to the sides of the vessel. The gas which remains has no odour like ammonia, nor colour like muriatic acid gas. It is not dissolved in water, nor does it maintain combustion; it is therefore nitrogen gas. In the bottom of the vessel there is found a clear and transparent liquid, which is water, holding a certain quantity of the muriate of ammonia in solution.

Rationale....Ammonia consists of nitrogen and hydrogen dissolved in caloric. Oxygenized muriatic acid gas consists of muriatic acid, oxygen, and caloric. On bringing the two gases into contact, a reciprocal decomposition takes place. The oxygen of the oxygenized muriatic acid gas combines with the hydrogen of the ammonia, and forms water; while the nitrogen, the other component part of the ammonia, becomes disengaged. The oxyge-

nized muriatic acid gas having lost its oxygen, becomes converted into simple muriatic acid gas, part of it unites to part of the ammonia (which in this experiment is present in too large a quantity to be wholly decomposed) and forms with it muriate of ammonia. The explosion, heat, and light, originate from the liberated caloric which kept the gases in their aeriform state.

REMARK....If a smaller portion of ammonia is added to the above quantity of oxygenized muriatic acid gas, its decomposition will be complete, and no muriate of ammonia be produced. The results then are only *muriatic acid* and *water*.

The same facts may be shown in the following manner:

EXPERIMENT VIII.

Fill four-fifths of a long glass tube with strong oxygenized muriatic acid, and the remaining fifth with water strongly impregnated with ammonia, and invert it in a saucer of water. The ammonia, on account of its lightness, will pass through the oxygenized muriatic acid; but by thus passing, a strong effervescence is produced, the elastic fluid by which it is occasioned collects in the upper part of the tube, and a portion diffuses itself in the vessel. The gas disengaged will be found to be nitrogen.

RATIONALE....The explanation of this experiment is analogous to the former.

EXPERIMENT IX.

*Decomposition of ammonia by means of black oxyd of manganese at a high temperature.**

If ammonia be made to pass over pounded black oxyd of manganese brought to a red heat in a Wedgwood's tube, connected, by means of another glass tube, with an empty bottle immersed in cold water or ice, abundance of red vapours will soon be produced, and these will be succeeded by white ones, condensing in the bottle into a bright transparent fluid, which has a pungent saline

* This is an experiment of Dr. Milner of Cambridge. T. C.

taste. If this liquid be distilled to dryness by a gentle heat, the product will be water. The residue in the retort is of a white colour. It fuses in the fire, detonates on ignited coals, and produces vapours of nitric acid by the affusion of sulphuric acid, or ammonia when saturated with lime. It is therefore nitrate of ammonia. The black oxyd of manganese has changed its colour, being turned to a pale brown, and no longer gives oxygen gas by the addition of heat.

RATIONALE...In this experiment the hydrogen of the ammonia unites to part of the oxygen given out by the black oxyd of manganese, and forms water. The nitrogen of the ammonia unites to another part of the oxygen, and produces nitric acid; this joins to a quantity of undecomposed ammonia, and forms nitrate of ammonia.

EXPERIMENT X.

Decomposition of ammonia by the electric spark.

For this purpose take a detonating tube, admit into it about a cubic inch of ammonia and pass through it a succession of electric discharges. When about 200 strong shocks have traversed the gas, it will have increased three times its original bulk. On admitting a small quantity of water, the gas will not, as before, be completely absorbed by this fluid, but a part will remain. Hence it appears that the gas has undergone a decomposition, and on examination it will be found that the chemical union of the hydrogen and nitrogen has been broken, and that they are only mechanically mixed.*

* It can also be decomposed by Galvanic processes, and by Potassium. T. C.

SULPHUREOUS ACID GAS.

PART XXVIII.

SEVERAL philosophers have paid attention to the properties of this gas and its combinations; but Berthollet was the first who published an accurate account of it, which Fourcroy and Vauquelin have lately investigated still more completely. Their paper (of which we have made use) is inserted in the *Annales de Chimie*, II. 54, and copied into *Nicholson's Journal*, vol. I. p. 318.

We have seen before, that when sulphur is united to oxygen it forms an acid. When the quantity of oxygen is sufficient to oxygenate a given quantity of sulphur completely, the result is a perfect acid, called sulphuric acid. We shall now see that if a less quantity of oxygen is made use of, the result is an imperfect acid, capable of taking the gaseous state. To this gaseous fluid we give the name of sulphureous acid gas. It becomes obvious from this, that sulphureous acid gas has the same relation to sulphuric acid as phosphorus acid has to the phosphoric acid. At least this gas occupies the middle place between sulphur and sulphuric acid, which will be more evident when we shall speak of the formation of acids.

SECT. I.

PROPERTIES OF SULPHUREOUS ACID GAS.

SULPHUREOUS acid gas is a permanently elastic aeriform fluid at the ordinary pressure and temperature of our atmosphere. Its odour is strong and suffocating. It cannot maintain combustion, nor the respiration of animals. Its weight is more than double that of atmospheric air. Its specific gravity, according to Bergman, is 0.00246, and 0.00251 according to Lavoisier. It is not inflammable. One hundred cubic inches of it weigh nearly 63 grains. It is composed, according to Fourcroy, of 85 sulphur and 15 oxygen. It is acid; it first reddens and then destroys the greater part of the vegetable colours. It exerts little action on the metals, and has a weak attraction to alkalies and earths. It has the property of whitening silk, and giving it a lustre. Priestley, Bergman, Berthollet, &c. say, that at high temperatures it deposits sulphur; but Fourcroy and Vauquelin, in consequence of some new experiments, deny this assertion. Phosphorus has no action upon it. Its attraction for oxygen when dry, at the common temperature, is very feeble; but if the smallest quantity of moisture be present, the union of the two gases is much favoured. At high temperatures the combination is more speedily effected. When a mixture of sulphureous acid gas and oxygen gas is made to pass through an ignited tube, the two gases combine, and sulphuric acid is formed. When passed into water cooled down to the freezing point, the union is very rapid. Water cooled to 40 degrees absorbs one third part of its weight of sulphureous acid gas. It speedily melts ice. Water saturated with it may be frozen without parting with its gas; but when water which has been saturated with it is exposed to heat, it is filled with a vast number of bubbles, which continually increase and rise to the surface; these bubbles are the gas separating from it. It is absorbed by oil, ether, and sulphuric acid; the latter when saturated with it acquires the property of emitting fumes when exposed to air; its colour is altered to a yellowish

brown, and its odour is penetrating, like that of the gas. When the acid thus saturated with the gas is exposed to a few degrees below the freezing point, it congeals or freezes into a crystalline mass. The same happens when submitted to distillation. It decomposes nitric and oxygenized muriatic acid, and dissolves camphor. Sulphureous acid gas and hydrogen gas have no action upon each other at common temperatures, but if they are passed through an ignited tube, a decomposition is effected. Charcoal likewise decomposes sulphureous acid gas at a high temperature. Monge and Clouet affirm, that by extreme artificial cold and a strong pressure exerted at the same time, they rendered sulphureous acid gas fluid.

METHODS OF OBTAINING SULPHUREOUS ACID GAS.

1. Take one part of mercury and four of concentrated sulphuric acid; put them into a glass retort connected with the pneumatic quicksilver trough, and apply the heat of a lamp to the mixture till it boils. On continuing the heat after the mercury has been acted upon, sulphureous acid gas will be obtained in abundance.

RATIONALE....In this case a partial decomposition of the sulphuric acid takes place. The mercury abstracts part of its oxygen, and becomes converted into an oxyd; the sulphuric acid, in consequence of the loss of oxygen, becomes converted into sulphureous acid, which takes the gaseous form at the common temperature.

2. Sulphureous acid gas may likewise be obtained by the slow combustion of sulphur.

Put pounded sulphur into a shallow earthen dish or crucible; melt and set fire to it; and when it is completely inflamed, cover it with a large bell glass perfectly dry; remove the whole on a dish, and surround the apparatus with mercury. The sulphur will burn for some time, and the bell glass will be filled with white vapour. When the vapour has subsided, the gas may be transferred as usual.

RATIONALE....During the burning of the sulphur in a confined quantity of atmospheric air, it absorbs the oxygen contained in it; this however not being sufficient

to oxygenate the sulphur completely, the result is an imperfect aeriform acid, or sulphureous acid gas.

3. Sulphureous acid gas may also be obtained by decomposing sulphite of potash or soda, either by heat alone, or by the affusion of acids.

4. If charcoal be moistened with sulphuric acid, and then exposed to distillation, the products are carbonic acid gas and sulphureous acid gas.

RATIONALE....During this operation the charcoal attracts part of the oxygen of the sulphuric acid, and forms carbonic acid gas. The sulphuric acid is therefore partly de-oxydated, and becomes converted into sulphureous acid gas.

5. Sulphureous acid gas is likewise formed by distilling sulphur with the oxyds of mercury, lead, tin, manganese, &c.

RATIONALE....In these processes the sulphur attracts the oxygen of the metallic oxyds and becomes converted into sulphureous acid gas, while the oxyds are partially restored to the metallic state.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF SULPHUREOUS ACID GAS.

EXPERIMENT I.

Sulphureous acid gas is heavier than atmospheric air, and does not maintain combustion.

This may be shown by dipping a lighted candle successively into a jar filled with this gas. The candle will be extinguished every time, though the jar filled with it continues exposed to the air.

EXPERIMENT II.

Sulphureous acid gas is rapidly absorbed by water.

Fill a cylinder with the gas over mercury, and send up into it a little water. The gas will instantly become diminished, and the mercury rises up in the vessel.

The absorption of this gas may likewise be shown by dipping the neck of the retort, in which it is disengaged, in a basin of cold water.

REMARK....The combination of sulphureous acid gas with water cooled artificially takes place with such rapidity, that not a single bubble of it rises to the top until the water is saturated. If ice be present in the water, it melts rapidly. The water at this temperature increases almost one seventh part in weight.

The saturated water when exposed to a temperature of about 65° or 70° Fahr. becomes filled with a multitude of small bubbles, which continually increase and rise to the surface. This may be shown in the following

EXPERIMENT III.

Disengagement of sulphureous acid gas from water saturated with it.

Take a bottle filled with water completely saturated with sulphureous acid gas at a low temperature, plunge it into a basin of hot water and uncork it; an infinite number of small bubbles will instantaneously be extricated, the water in the bottle will appear to boil with great rapidity and lose most of its gas.

RATIONALE....The sulphureous acid gas contained in the water is capable of remaining in combination with this fluid at low temperatures; but by the addition of caloric, becomes converted into the state of gas, which flies off, and occasions the apparent ebullition.

REMARK....Water that has absorbed sulphureous acid gas is to be looked upon as liquid sulphureous acid. It possesses the peculiar odour of the gas and an acid taste. At first it only reddens blue vegetable colours, but at last totally destroys them. The infusion of rose-leaves and several other vegetable pigments lose all their colour by it instantly.

EXPERIMENT IV.

Sulphureous acid gas and oxygen gas do not act upon each other at a low temperature without the intervention of a fluid.

To two parts of sulphureous acid gas, prepared in the mercurial apparatus, add one part of oxygen gas; no per-

ceptible union will take place even after some months: but if a small quantity of water be added to the mixture an absorption gradually takes place, the volume of the gases becomes diminished, and sulphuric acid is formed.

REMARK....The water presented acts as an intermediate body to favour the union of the two gases. Its great attraction for the sulphureous acid gas enables the oxygen to unite to it in order to convert it into sulphuric acid.

EXPERIMENT V.

Sulphureous acid gas and oxygen gas readily act upon each other at high temperatures.

In the last experiment we have seen that the two gases have no action upon each other at common temperatures, unless by the intervention of water; but if we transmit a mixture of sulphureous acid gas and oxygen gas through an ignited earthen tube placed across a furnace, very dense white fumes are formed, which become converted into liquid sulphuric acid, and may be collected in a vessel placed for that purpose at the other extremity of the tube.

RATIONALE...The oxygen gas at this temperature yields its oxygen to the sulphureous acid gas, and converts it into sulphuric acid, which it is only capable of doing in a direct manner at that temperature.

EXPERIMENT VI.

Hydrogen gas has no action upon sulphureous acid gas in the cold, but decomposes it at high temperatures.

When we mingle together hydrogen gas and sulphureous acid gas at common temperatures, there is no action; but if we transmit a mixture of three parts of hydrogen gas and one of sulphureous acid gas through a Wedgwood's tube in a state of ignition, sulphurated hydrogen gas will be evolved, and sulphur deposited at the extremity of the tube, opposite to that through which the gas is made to pass.

RATIONALE....Part of the hydrogen at such a temperature unites to the oxygen of the sulphureous acid gas to form water, the sulphur is consequently left uncombined; another part (or at least the excess) of the hydrogen dissolves a portion of the sulphur, and becomes converted into sulphurated hydrogen gas.

REMARK....The two last experiments are well calculated to demonstrate the nature of sulphureous acid gas. In the first it became changed into sulphuric acid by the addition of oxygen at a high temperature: in the other, hydrogen gas decomposes the sulphureous acid gas at the same temperature, by taking from it that portion of oxygen which kept it acid, and the sulphur is disengaged.

EXPERIMENT VII.

Formation of sulphate of ammonia by mingling sulphureous acid gas and ammoniacal gas.

Let sulphureous acid gas be mixed with ammoniacal gas over mercury; a beautiful white cloud will be formed by their combination, heat is liberated, and both gases gradually assume the solid state, forming sulphate of ammonia. If the gases have been pure, the mercury rises almost to the top of the vessel.

If the sulphureous acid gas be presented to the ammoniacal gas, the cloud is formed at the bottom, and gradually rises to the top; but if the ammoniacal gas be poured in last, the cloud rises immediately to the top. These consequences naturally result from the ammoniacal gas being the lightest.

RATIONALE....The white cloud formed in this experiment is sulphate of ammonia, which originates from the strong attraction these gases have for each other. The caloric which kept them in the gaseous state being set free produces the heat evolved during this union.

EXPERIMENT VIII.

Sulphuric acid saturated with sulphureous acid gas acquires a concrete form.

When sulphureous acid gas is made to pass into sulphuric acid cooled by a frigorific mixture, the gas is for a con-

siderable time absorbed by the acid, which at last acquires a solid form. The solid acid has no very perceptible odour. If part of it be laid upon a plate of glass, it exhibits an effervescence, like that occasioned by the decomposition of carbonate of lime by the affusion of a weak acid. It soon after becomes liquid and very odorous.

REMARK....We have therefore a concrete sulphuric acid, formed by the addition of sulphureous acid gas. Nitrous gas is also said to possess the same property. There is no doubt but that other concrete modifications occasioned by other gases will be discovered hereafter.

EXPERIMENT IX.

Decomposition of sulphureous acid gas by charcoal.

When sulphureous acid gas is passed through a tube containing ignited charcoal, carbonic acid gas and sulphurated hydrogen gas are obtained, and the inner surface of the tube is lined with sulphur.

RATIONALE....The charcoal at the temperature of ignition takes the oxygen from the sulphureous acid gas, and forms with it carbonic acid gas; the sulphur therefore becomes precipitated. The sulphurated hydrogen gas arises from a portion of water contained in the charcoal.

EXPERIMENT X.

Decomposition of sulphureous acid gas by muriate of tin.

Fill a cylinder with sulphureous acid gas, and pass up into it *fresh prepared* concentrated muriate of tin, the volume of the gas will soon become diminished, and sulphur be deposited.

RATIONALE....The oxyd of tin robs the sulphureous acid gas of its oxygen, and becomes converted into oxygenated muriate of tin, and the sulphur, deprived of its oxygen, is deposited.

MURIATIC ACID GAS.

PART XXIX.

SECT. I.

THE basis of this gas is still unknown. The presence of oxygen has not been even demonstrated in it, and it is only by analogy that we may venture to suppose it instrumental in this acid gas. Some philosophers have lately persuaded themselves that it is an oxyd of hydrogen. The experiments hitherto advanced are, however, not sufficient to prove this assertion.

PROPERTIES OF MURIATIC ACID GAS.

Muriatic acid gas has a very pungent and suffocating odour, which excites coughing. It is readily absorbed by water, by ardent spirit, ether, fat, and essential oils, melted wax, phosphorus, and many other bodies. It is a true acid. It suffocates animals, and is so very caustic as to excoriate the skin. It extinguishes a lighted taper, the flame of which becomes green, or rather light blue, at the upper part of its disk. Light has no effect upon it. Caloric rarefies it. It is heavier than common air. The specific gravity of the former is to that of the latter as 1.750 to 1.000. When brought into contact with atmospheric air, or oxygen gas, it forms a white cloud. Ice is melted by it as speedily as if thrown into the fire. It unites to alkaline and terrene substances, and forms with them new compounds. It has no action on siliceous earths. It combines with alumine and magnesia. It ab-

sorbs oxygen when in the state of gas feebly, though there are methods of uniting them readily. If ammoniacal gas be mixed with it and heat applied, both gases lose their gaseous form in a moment, and are transformed to a concrete salt. Carbonic acid gas, nitrogen gas, gaseous oxyd of nitrogen, sulphurated hydrogen gas, and carbonated hydrogen gas, have no action upon it. It has never been found in a disengaged state in nature. When electric explosions are made to pass through it, its bulk is diminished, and hydrogen gas is evolved. These changes are owing to a quantity of water contained in the gas, and cease when it is deprived of moisture, as has been proved by Mr. Henry.*

METHODS OF OBTAINING MURIATIC ACID GAS.

1. Muriatic acid gas may be obtained by decomposing muriate of soda by means of sulphuric acid. For this purpose, put into a tubulated retort two parts of very dry muriate of soda, and pour on it very gradually one part of concentrated sulphuric acid. A violent action takes place, and muriatic acid gas becomes liberated, which must be collected over mercury in the usual manner.

RATIONALE....The sulphuric acid has a greater affinity for the soda than the muriatic acid has; it therefore unites to it, and forms sulphate of soda. The muriatic acid being liberated takes the gaseous form, and appears as muriatic acid gas.

REMARK....As this decomposition takes place very rapidly, it is not necessary to apply heat until the disengagement of the gas begins to slacken, after which the further extrication may be assisted by the heat of a lamp.

2. Muriatic acid gas may likewise be obtained by expelling it from its combination with water.

For this purpose put concentrated muriatic acid into a retort, immerse the beak of it under a receiver placed in a mercurial pneumatic trough, and filled with that metal. On exposing the acid to a gentle heat, muriatic acid gas

* Nicholson's Journal, vol. IV. p. 209.

will be obtained. If the process be very carefully managed, nothing but water remains in the retort.

3. Muriatic acid gas is likewise produced by putting any quantity of liquid muriatic acid into a long glass tube, and adding to it about one-third or one-fourth, by measure, of concentrated sulphuric acid. A violent effervescence takes place, and the whole tube becomes filled with dense white vapours, which are muriatic acid gas, condensed again by means of the moisture in the atmosphere. The sulphuric acid added to the muriatic acid, deprives the latter of part of its water; a combination and penetration of the two liquids take place, and caloric is evolved, contributing to render the gas aeriform, which is thus forced to escape.

This experiment proves that the affinity of sulphuric acid for water is greater than that of muriatic acid.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF MURIATIC ACID.

Experiment I.

Muriatic acid gas is readily absorbed by water.

Fill a receiver with muriatic acid gas, and introduce into it a little water; the gas will speedily be absorbed, and the fluid exhibit all the properties of muriatic acid.

The absorption may also be shown by disengaging the gas in a retort, and dipping the neck into a basin of water, or letting it pass into a receiver moistened with a small quantity of this fluid.

Remark....Water when charged as highly as possible with this gas, forms the ordinary muriatic acid in a liquid state. Ten grains of water are capable of absorbing ten grains of the gas. The solution thus obtained occupies the space of 13.3 of water nearly. Water heated absorbs it with difficulty. The colder the water the more it absorbs.

Experiment II.

Muriatic acid gas melts ice speedily.

This experiment may be shown by passing the current of muriatic acid gas as it is disengaged into a vessel filled with ice, broken into small pieces. The ice will melt as rapidly as if heat were applied.

Rationale....The rapid liquefaction depends on the vast quantity of caloric which is evolved by the gas when returning from the gaseous to the liquid state, which becomes absorbed by the ice, and melts it.

Experiment III.

Muriatic acid gas when brought into contact with air forms white clouds.

If a wide-mouthed bottle be half filled with muriatic acid gas, and atmospheric air be admitted, by removing it from the mercury over which it was charged, the whole vessel will be instantly filled with dense white vapours, and a considerable degree of heat will be produced.

Rationale....The vapours are occasioned by the moisture in the air, to which the muriatic acid gas unites, in order to become converted into liquid muriatic acid, abandoning at the same time its combined caloric, which becoming free produces the heat.

Remark....The more humid the air, the denser the vapours are on presenting muriatic acid gas to it, and for that reason they are never produced on the summits of mountains or other places where the air is very dry.

This production of white vapour is therefore a sure sign of the humidity of the air.

Experiment IV.

Formation of muriate of ammonia by mingling muriatic acid gas and ammonia.

If muriatic acid gas and ammonia be mingled together in a cylinder over mercury, the mixture becomes in-

stantly heated, and a white cloud is formed. The mercury rises, and muriate of ammonia will be formed, which crystallizes on the internal surface of the receiver, during the subsiding of the white vapour. If the two gases are very pure and perfectly dry, they completely disappear, and the disengagement of caloric is considerable.

RATIONALE....The production of the muriate of ammonia is owing to the attraction of the bases of the two gases to each other being greater than that of the caloric which kept them in the gaseous state; they therefore abandon the caloric, unite, and form a solid combination called muriate of ammonia.

EXPERIMENT V.

Muriatic acid gas extinguishes the flame of burning bodies; first enlarging it by the addition of a green or bluish circumambient flame.

If a lighted taper be let down into a receiver filled with muriatic acid gas, the flame will be extinguished; but before its extinction it will be enlarged by a green or bluish circumambient flame.

REMARK....This curious phenomenon has not yet been satisfactorily explained.

OXYGENIZED MURIATIC ACID GAS.

PART XXX.

SECT. I.

WHEN the muriatic acid gas before mentioned becomes combined with a certain quantity of oxygen, the result is an expansible gaseous fluid, to which chemists have given the name of oxygenized muriatic acid gas.

PROPERTIES OF OXYGENIZED MURIATIC ACID GAS.

Oxygenized muriatic acid gas possesses an uncommonly pungent and suffocating odour. It is absolutely and in every respect non-respirable; animals immersed in it die instantly. It is absorbable by water, and forms with it what is called liquid oxygenized muriatic acid. When water is saturated with it, the compound crystallizes at low temperatures. Oxygenized muriatic acid gas is not *invisible*, but has a *yellow-greenish colour*. It is capable of maintaining and exciting combustion in many cases. Phosphorus, charcoal, red sulphuret of mercury, sulphuret of antimony, bismuth, iron, zinc, copper, gold, arsenic, cobalt, tin, lead, and several other combustible bodies, take fire spontaneously when introduced into it. It is heavier than atmospheric air. It weakens and reddens the flame of a taper, but does not extinguish it. It decom-

poses ammonia. It thickens fat oils. It detonates with hydrogen gas. Nitrous gas immediately produces a cloud of reddish vapour with it. It is likewise decomposed by sulphurated, phosphorated, and carbonated hydrogen gases. It is not altered by exposure to light, and passes unaltered through an ignited porcelain tube. It discolours stuffs, and totally destroys most of the vegetable colours, rendering them white. It also bleaches yellow wax, &c.

METHODS OF OBTAINING OXYGENIZED MURIATIC ACID GAS.

1. Put into a retort one part of powdered black oxyd of manganese and three or four of concentrated muriatic acid; connect the retort with a pneumatic trough, and receive the gas *over water** in the usual manner. When no more gas is liberated, apply the heat of the lamp, and gas will be produced abundantly, which may be kept in bottles with ground glass stoppers.

RATIONALE....The oxyd of manganese yields up part of its oxygen to part of the muriatic acid, which becomes converted into oxygenated muriatic acid gas; the oxyd of manganese being thus partly deoxydated, is dissolved in the remaining quantity of the muriatic acid, which is left in the retort as muriate of manganese.

REMARK....The retort containing the mixture should not be filled above one third; for the fluid on the application of heat swells, and is otherwise very apt to be forced over into the neck of the retort.

2. Oxygenized muriatic acid gas may likewise be obtained in an indirect manner, by decomposing muriate of soda in contact with black oxyd of manganese. For that purpose mix eight parts, by weight, of muriate of soda with three of powdered oxyd of manganese, put the mixture into a tubulated retort, and pour upon it gradually four parts of sulphuric acid, diluted previously with three of water, and which has been suffered to cool after dilution. On applying a gentle heat, gas will be produced as before.

* Though mercury is generally made use of in this process, water answers the purpose better.

RATIONALE....In this operation the sulphuric acid acts on the muriate of soda, to the base of which it unites; the muriatic acid formed by this union attacks the oxyd of manganese; one part of it combines with the oxygen, and another with the oxyd brought nearer to the metallic state; and the result is sulphate of soda and muriate of manganese, which remain in the distilling vessel; and oxygenized muriatic acid, which passes in the state of gas at common temperatures.

REMARKS....In preparing this gas great care should be taken that it does not escape into the apartment in any considerable quantity; as it acts violently on the pituitous membrane, occasions a defluxion of the brain, blunts the senses of smell and taste, produces head-ache, and proves extremely injurious to health.*

Pelletier fell a sacrifice in attempting to breathe it; a consumption was the consequence, which proved fatal.

Liquid ammonia is the remedy best calculated to check its effects, when accidentally set at liberty in places where it is prepared.

The film of water which adheres to the inner side of the vessel filled with oxygenized muriatic acid gas crystallizes in the form of yellow spangles, if the temperature is near the freezing point. If a considerable quantity of gas be thus condensed, care must be taken to keep it at a low temperature, for as soon as it becomes heated it expands, and endangers the bursting of the vessel.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF OXYGENIZED MURIATIC ACID GAS.

EXPERIMENT I.

Oxygenized muriatic acid gas is absorbed by water.

Fill a phial with oxygenized muriatic acid gas, and agitate it strongly in contact with water; a rapid absorption takes place, and the water will ascend in the phial.

* This gas can also be procured by substituting red lead (minium) for manganese. But the best method is to put into a retort three parts by weight of common salt, one part of finely powdered manganese, and two parts of oil of vitriol diluted with thrice its bulk of water. T. C.

It acquires the colour and odour of the gas, and the property of discharging vegetable colours.

Experiment II.

Oxygenized muriatic acid gas destroys vegetable colours and renders them white.

Fill a vessel with oxygenized muriatic acid gas, and introduce into it a sprig of mint, a rose, &c. Its colour will soon be destroyed, and the gas diminished.

All flowers of variegated colours and green leaves of plants are in time rendered white by it; and no alkali is capable of restoring their colour.

Rationale....This effect can be ascribed only to the absorption of oxygen. This gas, which contains it in excess, gives up a part of it, which vegetable substances absorb with avidity; and by this absorption lose their colour: the oxygenized muriatic acid gas then becomes converted into common muriatic acid gas.

Remark....It is this property which induced a new method of bleaching, which has proved completely successful. The advantages which result from this application of the oxygenized muriatic acid, either in the gaseous or the liquid state, have accelerated the process of whitening thread, cotton, linen, wax, &c. to a really surprising degree, in every season of the year, and can be justly appreciated by commercial people only, who experience its beneficial effects from the quick circulation of their capitals.

Experiment III.

Bleaching of linen, calico, &c. by oxygenized muriatic acid gas.

Suspend some unbleached calico or linen, moistened with water, in a jar filled with oxygenized muriatic acid gas. The natural colour of the stuff will soon begin to fade, and at last totally disappear.

If different coloured patterns of calico or printed cotton be immersed for a few minutes into the gas, their colours will soon be destroyed, except those which are yellow.

Experiment IV.

Oxygenized muriatic acid gas supports flame.

Though oxygenized muriatic acid gas is exceedingly noxious to life, it does not extinguish combustion.

If a burning taper affixed to a wire be immersed in it, the taper burns of a red colour, and more vividly than in atmospheric air; a great quantity of smoke is emitted at the same time.

Experiment V.

Spontaneous accension of metals in oxygenized muriatic acid gas.

Fill a tall receiver furnished with a ground stopper with oxygenized muriatic acid gas, over water, and let fall into it copper beaten out into a thin leaf (Dutch gold.) The copper leaf before it reaches the bottom of the receiver will burn with a pale green light.

Gold leaf may be burnt in a similar manner.

Fine copper wire when heated to redness also takes fire when introduced into the gas in that state.

Other metals may be inflamed in oxygenated muriatic acid gas in the following manner.

Experiment VI.

Fill a tall bell-glass, furnished with a stopper, or cork, at the top, with oxygenized muriatic acid gas, and throw into it, in small quantities, either some antimony or arsenic reduced to fine powder. The metal introduced will instantly inflame, and appear like a shower of fire.

Tin, cobalt, bismuth, nickel, copper, &c. reduced to a fine powder, may be inflamed in a similar manner.

Rationale....The metals presented to the oxygenized muriatic acid gas rapidly subtract its oxygen, and become converted into oxyds; the combined light and heat of both the gas and the metal are disengaged, and appear under the form of fire; and the oxygenized muriatic acid gas returns to the state of simple muriatic acid gas.

REMARK....To succeed well in making these experiments, it is necessary that the metal should be reduced to a fine powder, and employed in the proportion of a grain, to two or three cubic inches of gas. The gas made use of should be perfectly fresh prepared. If the gas be warmed a little, the phenomena never fail. Iron, lead, and zinc, are more difficult to inflame than any of the former; it frequently happens that they remain unaltered at the bottom of the vessel for some time, but on a sudden the accension takes place. Nickel, arsenic, and bismuth are the metals which are most readily inflamed, and which burn most brilliantly.

EXPERIMENT VII.

Spontaneous accension of phosphorus in oxygenized muriatic acid gas.

Put a piece of phosphorus, dried on blotting-paper, into a copper ladle, and introduce it into a jar filled with oxygenized muriatic acid gas; the phosphorus will instantly kindle, and burn with a greenish white light.

RATIONALE....The phosphorus unites with the oxygen of the oxygenized muriatic acid gas, and becomes converted into phosphoric acid; the oxygenized muriatic acid gas, by thus losing its oxygen, returns to the state of muriatic acid gas.

EXPERIMENT VIII.

Spontaneous accension of sulphur in oxygenized muriatic acid gas.

If a piece of sulphur be presented to oxygenized muriatic acid gas, no action ensues; but if we *melt* a little sulphur in a ladle, and then introduce it, in a state of perfect liquidity, into a jar filled with this gas, the sulphur takes fire, and burns rapidly.

RATIONALE....The explanation of this experiment is analogous to the former ; the sulphur decomposes the oxygenized muriatic acid gas, and becomes converted into sulphuric acid : but before that effect can take place, the attraction of cohesion of the particles of sulphur must be demolished, that is to say, the sulphur must be rendered fluid, which was not necessary with phosphorus.

EXPERIMENT IX.

Spontaneous accension of metallic sulphurets by oxygenized muriatic acid gas.

Sulphuret of antimony reduced to a fine powder, and introduced into the gas, in the same manner as was directed for the accension of the metals, will also take fire.

A similar effect is produced by this gas on sulphuret of mercury, iron, &c.

A variety of other combustible substances may also be inflamed by presenting them to oxygenized muriatic acid gas in its nascent state, as was first shown by professor Davy.*

EXPERIMENT X.

Accension of ether, alcohol, or oil of turpentine, by oxygenized muriatic acid gas in its nascent state.

Put into a wine-glass one part of oxygenated muriate of potash perfectly dry, and pour on it two or three of colourless sulphuric acid of commerce ; a violent action will take place, and oxygenized muriatic acid gas be evolved. If, during the extrication of this gas, one part of sulphuric ether, alcohol, or oil of turpentine, be suffered to fall into the gas, an accension takes place accompanied with a crackling noise.

REMARK....In this manner not only all the inflammable fluid bodies, but likewise most of the solids, such as camphor, resin, tallow, pitch, elastic gum, &c. may easily be inflamed.

* Nicholson's Journal, April 1802, p. 296.

Experiment XI.

Accension of expressed oils at the surface of water by oxygenized muriatic acid gas.

Put into a glass cylinder one part of oxygenated muriate of potash; add to it three or four of water, and half a part of oil of olives, or of linseed. On adding to it four or five parts of concentrated sulphuric acid, a violent action takes place, much charcoal becomes deposited, and a multitude of ignited sparks pass through the black fluid, exhibiting a beautiful phenomenon. On adding an additional quantity of oxygenated muriate of potash and sulphuric acid, the whole mass takes fire, and burns with a dense yellow flame.

Experiment XII.

Accension of phosphorus in oxygenized muriatic acid gas, under the surface of water.

Let fall into a wine glass, or rather into a long cylinder, two thirds filled with water, one part of phosphorus, and two of oxygenated muriate of potash. On adding to this mixture gradually three or four parts of sulphuric or nitric acid, the phosphorus takes fire, and burns vividly *under the surface* of the fluid: on agitating the mixture, streams of ignited sparks pass through the water rapidly.

Remark....This and the two preceding experiments require caution. The operator ought to be distant during the affusion of the acids, or the addition of the combustible body, which are sometimes thrown out of the vessel to a considerable distance.

Experiment XIII.

Nitrous gas and oxygenized muriatic acid gas readily unite and produce nitro-muriatic acid.

This may be shown by sending up into a receiver filled with oxygenized muriatic acid gas, bubbles of nitrous gas;

the mixture becomes warm, reddish fumes appear, and nitro-muriatic acid is produced.

RATIONALE....The nitrous gas takes part of the oxygen from the oxygenized muriatic acid gas, and becomes converted into nitrous acid; it then unites to the oxygenated muriatic acid gas, and forms with it nitro-muriatic acid.

EXPERIMENT XIV.

Decomposition of oxygenized muriatic acid gas by ammonia.

If fresh prepared oxygenized muriatic acid gas and ammonia be mingled together over mercury, a rapid detonation takes place, accompanied with a white flame, and the receiver becomes filled with dense white vapours.

RATIONALE....The oxygen of the oxygenized muriatic acid gas unites to the hydrogen of the ammonia, and produces water; whilst the nitrogen of the ammonia is liberated, and the oxygenated muriatic acid gas becomes converted into simple muriatic acid.

REMARK....This experiment requires caution. The cylinder in which the gases are mingled should be very strong, and the gases should be mixt in small quantity. The experiment succeeds exceedingly well, if about eight cubic inches of ammonia are sent up into a jar holding at least fifty cubic inches of oxygenized muriatic acid gas. (*See Appendix No.* 29.)

FLUORIC ACID GAS.

PART XXXI.

SECT. I.

THE composition, or the radical, of fluoric acid gas is equally unknown; for no experiments have yet been made by which it can be exhibited. It is merely from general inference that we may conjecture it to consist of a simple acidifiable base united to oxygen.

PROPERTIES OF FLUORIC ACID GAS.

The most remarkable property of this gas is its power of dissolving silex, and keeping it suspended in the gaseous state; it therefore dissolves glass, crystals, and various precious stones. It is heavier than atmospheric air. It does not maintain combustion, nor can animals breathe it. It is absorbed by water, and forms with it liquid fluoric acid. It has a penetrating odour, approaching nearly to that of muriatic acid gas. It corrodes animal and vegetable matters. Light has no effect upon it. It emits white fumes in contact with moist atmospheric air. It is very sour, and therefore reddens blue vegetable colours. It precipitates lime water. With ammonia it unites, and forms a concrete body. It has no action upon platina, gold, silver, mercury, tin, lead, antimony, cobalt, nickel, or bismuth; but it attracts iron, arsenic, and manganese.

METHODS OF OBTAINING FLUORIC ACID GAS.

1. Fluoric acid gas may be obtained by decomposing fluate of lime (Derbyshire spar) by means of sulphuric acid.

For that purpose, put one part of powdered fluate of lime into a leaden or tin retort, and pour over it two or three parts of concentrated sulphuric acid. A violent action takes place instantly, and fluoric acid gas is extricated, which must be collected over mercury, either in a leaden or tin vessel, or in a glass receiver covered within with a thick coat of varnish or wax. When no more gas is produced spontaneously, the action of the acid must be assisted by a gentle heat.

RATIONALE....Fluate of lime consists of fluoric acid united to lime; on adding sulphuric acid, a decomposition takes place. The sulphuric acid having a greater attraction for the lime than the fluoric acid has, unites to it and forms sulphate of lime, disengaging at the same time the fluoric acid, which takes the gaseous state at the instant of its extrication, and appears under the form of fluoric acid gas.

2. Fluoric acid gas may likewise be obtained from liquid fluoric acid (water impregnated with fluoric acid gas) by heat.

SECT. II.

EXPERIMENTAL PROOFS OF THE PROPERTIES OF FLUORIC ACID GAS.

EXPERIMENT I.

Fluoric acid gas is absorbable by water.

INTRODUCE into a receiver coated within with wax, and filled with fluoric acid gas, a little water, and agitate it; heat will be produced, the gas will vanish, and the mercury rise into the receiver.

If the water be examined, it will be found to possess all the properties of fluoric acid; it will corrode glass, flint, quartz, and other siliceous substances. If it be exposed to heat, part of the absorbed gas becomes extricated again; but the last portion adheres to it so strongly, that the water and the rest of the acid are volatilized if the heat be increased.

Experiment II.

Fluoric acid gas extinguishes light and kills animals.

If a lighted taper be plunged into a vessel filled with this gas, it will instantly be extinguished. An animal thrown into it soon dies.

Experiment III.

Fluoric acid gas dissolves silex, glass, quartz, &c.

This may be proved by disengaging fluoric acid gas from a leaden or tin retort, and collecting the gas in a common dry glass receiver. The gas as it enters the vessel acts upon the silex of the glass, and the receiver becomes opaque, by reason of its internal surface being corroded.

Remark....This property of dissolving silex has given the idea of etching on glass, either by means of the fluoric acid gas or liquid fluoric acid.

Experiment IV.

To etch upon glass by means of fluoric acid gas.

Take a pane of glass, clean it well, and cover it over either with a thin coat of bees wax, isinglass dissolved in

water, or engravers varnish. When it is dry, trace upon it, by means of a graver or any other sharp pointed instrument, any subject you choose: having done this, take some powdered fluate of lime, put it into a leaden basin, and pour over it a sufficient quantity of sulphuric acid, stirring it with a stick or slip of lead; then hold the pane of glass close over it, in order that the gas which is disengaged may act upon the glass, which will soon become corroded, and appear like engraven when the varnish or coating is removed. To assist the action of the sulphuric acid, the basin containing the mixture may be held over a lamp, or gentle coal fire.

This property of fluoric acid gas may be advantageously employed for engraving labels on glass bottles intended to contain acids; for graduating glass tubes, thermometers, &c. for ornamenting glass vessels; for removing injured enamels, &c.

REMARK....The art of etching on glass, which is generally considered as of modern date, does not entirely belong to our cotemporaries; even to assert that the ancients were altogether unacquainted with it would be unjust. It seems rather that this art belongs to the discoveries which were made in those times in which men were little inclined to transmit an account of their inventions to posterity, and thus may have been forgotten or lost. Scheele discovered the fluoric acid, and re-invented the art of etching on glass in 1771. But that it was practised a century before by a German, whose name was *Swanhard*, we have endeavoured to prove in *Nicholson's Journal for April*, 1803. Had this person been able to pursue properly the discovery which either accident or ingenuity presented to him, he might have enriched us with an art which acquired great reputation to Scheele a hundred years after.

EXPERIMENT V.

Fluoric acid gas not only dissolves, but also volatilizes siliceous earth.

This may be shown by decomposing fluate of lime in a glass retort, and receiving the gas in a vessel filled with

water, and resting upon mercury. Each bubble of the gas which passes through the mercury into the water becomes immediately enveloped in silex, and leaves, as it ascends to the surface of the water, traces in the form of tubes, which frequently decrease to a point upwards, because the bubble diminishes in proportion as the water dissolves it, and the silex is carried off.

RATIONALE....The gas when disengaged in the glass retort dissolves part of the silex of that vessel, which it keeps in an aeriform state. On coming into contact with the water it abandons its caloric, and becomes converted into liquid fluoric acid, depositing at the same time the siliceous earth.

REMARK....If substances capable of retaining moisture be exposed to fluoric acid gas, holding silex in solution, the water they contain will absorb the acid, and the siliceous earth will be precipitated upon them. In this manner lizards, frogs, moist fruits, bits of sponge, &c. may be encrusted with a coat of silex. Objects thus covered with a close and very hard siliceous crust greatly resemble petrifactions, and may be preserved for a long time.

PHOSPHORATED CARBONATED HYDROGEN GAS.

In Van Mons's Journal de Chimie et de Physique, p. 213, is published an account of a new species of gas discovered by professor Tromsdorf, which is composed of hydrogen, carbon, and phosphorus. It was obtained by this gentleman during the de-oxydation of phosphoric acid by charcoal, in the common process of distilling phosphorus. Its weight is nearly equal to that of atmospheric air. It is not absorbed by water; oxygen has no effect upon it at common temperatures, but explodes with it by the electric spark. It has no action on metallic oxyds, but decomposes the solutions of gold, silver and mercury. The products after its detonation with oxygen are carbonic acid gas, phosphoric acid, and water. From these

results professor Tromsdorf proposes to call it phosphorated carbonated hydrogen gas.

No further account of this gas having as yet reached us, we are not enabled to enter more fully into the subject; but as the learned professor has promised to investigate its properties, and publish the results, we may expect to be acquainted with it shortly.

THEORIES OF COMBUSTION.

PART XXXII.

AMONG the various operations of chemistry, none acts a more conspicuous part than combustion; and in proportion to its utility in the science, the necessity of thoroughly investigating its nature and mode of action becomes more obvious to the philosophical chemist. It was a conviction of the importance of this inquiry which induced Lavoisier to examine with accuracy the labours of his predecessors, and by this pursuit he was enabled to form a theory of this process, which though not absolutely free from error, was such as well entitled its author to the distinguished rank he holds among philosophers. And as this theory, though capable of improvement, will probably serve for a foundation to every discovery which may be made in this branch of the science, we shall state it here with a view that our readers may be enabled to appreciate its value.

SECT. I.

LAVOISIER'S THEORY OF COMBUSTION.

(SEE APPENDIX NO. 30.)

LAVOISIER'S theory of combustion is founded upon the absorption of oxygen by a combustible body.

We have seen that bodies cannot burn in a limited quantity of air beyond a certain period (p. 260) that a real analysis of this fluid is effected; and that combustion is not confined to the decomposition of the atmosphere only, by absorbing one of its principles; but that it also decomposes oxygen gas, by absorbing, fixing, and rendering more or less solid in the combustible body, the oxygen or basis of the oxygen gas, and disengaging its solvent, the caloric, under the appearance of heat and flame. *See p.* 228.

Taking this for granted, it follows that combustion is only the play of affinity between oxygen, the matter of heat, and a combustible body.

When an *incombustible* body, a brick for instance, is heated, it undergoes no change except an augmentation of bulk and temperature, and when left to itself it soon regains its former state. But when a *combustible* body is heated to a certain degree in the open air, it begins to become on a sudden intensely hot, and at last emits a copious stream of caloric and light to the surrounding bodies. During this emission the burning body gradually wastes away. It either disappears entirely, or its physical properties become totally altered. The principal change it suffers is that of being no longer capable of combustion.

If either of these phenomena, namely, the emission of heat and light, and the waste of substance, be wanting, we do not say that a body is undergoing combustion, or that it is burning.

It follows therefore that every theory of combustion ought to explain the following facts:

1. Why a burning body is consumed, and its individuality destroyed.

2. Why, during the progress of this alteration, heat and light are emitted.

For the elucidation of these objects, Lavoisier's theory has laid down the following laws:

1. Combustion cannot take place without the presence of oxygen, and is more rapid in proportion to the quantity of this agent in contact with the inflamed body.

2. In every act of combustion the oxygen present is consumed.

3. The weight of the products of every body after combustion corresponds with the weight of the body before combustion, *plus* that of the oxygen consumed.

4. The oxygen absorbed by the combustible body may be recovered from the compound formed, and the weight regained will be equal to the weight which disappeared during the combustion.

5. In every instance of combustion, light, and heat, or fire, are liberated.

6. In a limited quantity of air, only a certain quantity of the combustible body can be burnt.

7. The air, wherein a body has been burnt, is rendered unfit for maintaining combustion, or supporting animal life.

Though every case of combustion requires that light and heat should be evolved, yet this process proceeds very differently in different circumstances: hence the terms *ignition*, or glowing heat; *inflammation*, or accension; and *detonation*, or explosion.

IGNITION

Takes place when the combustible body is not in an aeriform state.

Charcoal, pyrophorus, &c. furnish instances of this kind.

It seems as if the phenomenon of glowing was peculiar to those bodies which require a considerable quantity of oxygen to become converted into the gaseous state.

The disengagement of caloric and light is rendered more evident to the senses in the act of

INFLAMMATION,

Or Accension. Here the combustible substances are more easily converted into an elastic or aeriform state. Flame therefore consists of the inflammable matter in the act of combustion in the gaseous state. When all circumstances are favourable to the complete combustion of the products, the flame is perfect; if this is not the case, part of the combustible body, capable of being converted into the gaseous state, passes through the luminous flame unburnt, and exhibits the appearance of smoke. Soot therefore always indicates an imperfect combustion. Hence a common lamp smokes, an Argand's lamp yields no smoke.

This degree of combustion is very accurately exemplified in the

FLAME OF CANDLES.

When a candle is first lighted, which must be done by the application of actual flame, a degree of heat is given to the wick sufficient to destroy the affinity of its constituent parts; part of the tallow is instantly melted, volatilized, and decomposed; its hydrogen takes fire, and the candle burns. As this is destroyed by combustion another portion melts, rises, and supplies its place, and undergoes a like decomposition. In this way combustion is maintained. The tallow is liquefied as it comes into the vicinity of the flame, and is by the capillary attraction of the wick drawn up to supply the place of what is decomposed; the unmelted tallow by this means forms a kind of cup.

The congeries of capillary tubes which form the wick is black, because the charcoal of the cotton becomes predo-

minant, the circumambient air is defended by the flame from oxydating it; it therefore remains for a considerable time in its natural state; but when the wick by the consumption of tallow becomes too long to support itself in a perpendicular position, its upper extremity projects nearly out of the cone of the flame, and there forms a support for an accumulation of soot, which is produced by the imperfect combustion. A candle in this situation affords scarcely one tenth of the light it can give, and tallow candles on this account require continual snuffing.

But if the candle be made of wax, the wick does not long occupy its place in the middle of the flame; its thinness makes it bend on one side when its length is too great for its vertical position; its extremity comes then in contact with the air, and is completely burnt or decomposed, except so much of it as is defended by the continual afflux of the melted wax. This small wick therefore performs the office of snuffing itself. The difficult fusibility of wax enables us to use a thinner wick for it than can be used for tallow, which is more fusible. But wax being a substance which contains much more oxygen than tallow or oil, the light it affords is not so luminous.

DETONATION

Is an instantaneous combustion, accompanied with a loud report; it takes place in general when the compound resulting from the union of two or more bodies occupies less space than the substances did before their union; a vacuum is therefore formed, and the surrounding air rushing in from all sides to fill it up is the cause of the report.

Gun-powder, fulminating gold, silver, and mercury, oxygenated muriate of potash, and various other explosive compounds, are capable of producing very loud detonations, as we shall see hereafter.

Let us now consider the disengagement of light and caloric.

By the older chemists it was universally supposed that the light and heat emitted during combustion proceeded from the inflammable body; and this opinion would indeed appear unquestionable while the composition of the atmosphere was imperfectly known. The burning body appeared luminous and felt hot, and no other agent was supposed to be concerned: the conclusion that the light and heat were evolved from the burning substance was therefore unavoidable.

But when the nature of the atmosphere was ascertained, and when it became evident that part of the air was absorbed during combustion, the former conclusion fell to the ground. For when two bodies exert a mutual action on each other, it becomes *a priori*, equally probable that the products may be derived from either of them; consequently the light and heat evolved might proceed either from the one or the other. Whether they proceed from the atmosphere or from the combustible body, they must be separated at the part where the combination takes place; that is, upon the surface of the burning body itself; and consequently it appeared luminous and heated, while the air being invisible, escaped observation.

When the laws of heat became known, at least when it was ascertained that bodies in the aeriform state contain at the same temperature, and in equal quantities, either of mass or bulk, unequal quantities of heat, the conclusion became probable, that the caloric evolved in combustion proceeded rather from the oxygen gas of the atmosphere than from the combustible body; since the former contains a much larger quantity than the latter. The caloric evolved was therefore supposed to be derived from the *condensation* of the oxygen gas in the new combination into which it entered.

Though *approaching* to the truth, this explanation is not strictly true. It is not merely from the oxygen gas being *condensed* that the caloric is evolved, because in many cases of combustion the product still exists in the gaseous state, and in others the quantity of caloric evolved bears no proportion to the degree of condensation. Philosophers ascribed this to a change of capacity, for in different bodies the difference in the proportion of the capacities before and after combustion is by no means

uniform, and hence the difference in the quantities of caloric extricated in various cases of combustion.

This being premised, it remains to explain the origin of the light emitted during combustion; for although we take it for granted that the caloric is evolved from the oxygen gas, we cannot infer that the light has the same origin.

It is very probable that light is a constituent part of inflammable bodies; for it is frequently evolved in combinations when the oxygen is merely *transferred* from one inflammable substance to another. In those cases it must proceed from the inflammable body. The accension of oils by the affusion of acids (page 51) the combustion of metals with sulphur (page 185) furnish instances of the kind.

It seems therefore probable that the light is derived from the inflammable substance; and that the oxygen combining with the bases of these substances disengages the light. It is *possible* that part of it may also be derived from the oxygen gas, but it is evidently unnecessary to *suppose so.*

It may be concluded then that light enters into the composition of all combustible bodies; but as we are unable to separate the light so as to obtain these bodies pure, we treat of them as simple bodies.

According to this theory, the combustion of phosphorus in oxygen gas (page 228) is therefore the effect of a double affinity. The basis of the oxygen gas unites with the phosphorus to form phosphoric acid; and the light disengaged from the phosphorus, together with part of that of the oxygen gas, produces the vivid flame.

The quantity of light emitted by different bodies is supposed to depend on the quantity contained in them, and on the proportion in which it is united to caloric.

Such is the theory of combustion of Lavoisier, modified by Dr. Parr, Gren, Leonhardi, Richter, &c.

Other teachers consider this theory as a modification of the old doctrine of Stahl, saying that light is substituted for phlogiston; but this is a mere verbal conceit which probably only originates from the prejudice which the partisans harbour in favour of the original theory of Lavoisier.

SECT. II.

THOMSON'S THEORY OF COMBUSTION.

Though the preceding theory of combustion is simple and beautiful, it appears, from what we are now going to state, to be by no means satisfactory.

It has misled chemists by confining the term combustion to the act of oxygenation, and considering that all bodies, during their combustion, combine with oxygen; without at the same time recollecting, that this latter effect may take place without any of the phenomena usually attendant on combustion; and that, though certainly all combustion pre-supposes the combination of oxygen with a base, yet this combination *may be*, and repeatedly *is*, effected where no combustion *can possibly* take place. Nothing can be more evident than the difference which in numberless instances prevails between the act of oxygenation in bodies and that of combustion, in as much as neither the phenomena attending on, nor the results arising from, them are the same. That a distinction therefore should be made between these processes is obvious; and it is on this account that Dr. Thomson has offered a theory which considers this subject in a new point of view, and which bids fair to enable us to estimate the phenomena of combustion much better than has hitherto been done.

According to Dr. Thomson's* theory, all the bodies concerned in combustion are either, 1. *Combustibles*, 2. *Supporters of Combustion*, 3. *Incombustibles*.

I. COMBUSTIBLE BODIES are those substances which are said in common language to *burn*. During the combustion they appear to emit light and heat, and at the same time gradually waste away. When this change has reached its *maximum*, the process of combustion is at an end.

* Nicholson's Journal, 1802, No. V. p. 10.

The class of combustibles is very numerous; but all the bodies belonging to it may be sub-divided into three sets, namely;

1. Simple combustibles,
2. Compound combustibles,
3. Combustible oxyds.

Simple Combustibles.

1. SULPHUR.
2. PHOSPHORUS,
3. DIAMOND,
4. HYDROGEN GAS,
5. ALL THE METALS.

Compound Combustibles.

The *compound combustibles* consist of compounds, formed by the simple combustibles uniting together two and two, and are of course much more numerous than the simple combustibles. They may be arranged under the five following heads:

1. SULPHURETS,
2. PHOSPHURETS,
3. CARBURETS,
4. ALLOYS,
5. SULPHURATED, PHOSPHORATED, AND CARBONATED HYDROGEN.

The *combustible oxyds* are either simple, having a single base, or compound, having more than one base. All the simple combustible oxyds are by combustion converted into acids.

The compound combustible oxyds are by far the most numerous.

II. The SUPPORTERS of COMBUSTION are bodies which are not of themselves, strictly speaking, capable of undergoing combustion, but which are absolutely necessary for the process; for no combustible body can burn unless some one or other of them be present. Whenever they

are excluded, combustion ceases. All the supporters of combustion known at present are the following six:

1. OXYGEN GAS, 2. AIR,
3. GASEOUS OXYD OF NITROGEN,
4. NITROUS GAS, 5. NITRIC ACID,
6. OXYGENIZED MURIATIC ACID.

There are indeed certain substances besides these which possess nearly the same properties; these shall be afterwards enumerated under the title of *partial supporters.*

They all contain one common principle, namely, *oxygen.*

III. The INCOMBUSTIBLE BODIES are neither capable of undergoing combustion themselves, nor of supporting the combustion of those bodies that are; they are therefore not immediately connected with combustion. At present we are acquainted with about 13 incombustible bodies, not reckoning the compounds which they are capable of forming with each other. These are,

1. NITROGEN GAS, 2. THE ALKALIES,
3. THE EARTHS.

Some of the alkalies and earths possess certain properties in common with combustibles, and are capable of exhibiting phenomena somewhat analogous to combustion; which will be described afterwards under the title of *semi-combustion.*

3. In every case of combustion there must therefore be present a *combustible* body, and a *supporter* of combustion. During combustion, the combustible always unites with the oxygen of the supporter. *It is this combination which occasions the apparent waste and alteration of the combustible.* The new compound thus formed is a *product of combustion.* Every product of combustion is ei-

ther, 1. *water*, or 2. *an acid*, or 3. *a metallic oxyd.* It is true indeed, that other bodies sometimes make their appearance during combustion, but these will be found upon examination not to be products, nor to have undergone combustion.

Thus one of the two characteristic marks which distinguish combustion, namely, the apparent *waste and alteration of the combustible body*, has been fully explained. For the explanation of it we are indebted to Lavoisier, as stated before.

But though the combination of the combustible with oxygen be a constant part of combustion, yet the facility with which combustibles burn is not proportional to their apparent affinity for oxygen.

Phosphorus, for instance, burns more readily than charcoal; yet charcoal is capable of abstracting oxygen from phosphorus, and of course has a greater affinity for it. The combustible oxyds take fire more readily than some of the simple combustibles; thus charcoal burns more easily than diamond: alcohol, ether, and oils, are exceedingly combustible, whereas all the metals require very high temperatures when the supporter is air.

This greater combustibility of combustible oxyds is probably owing to the weaker affinity by which their particles are united. Hence they are more easily separated than homogeneous particles, and of course combine more readily with oxygen; those simple combustibles which melt easily, or which are in the state of elastic fluids, are also very combustible, because the cohesion between their particles is easily overcome.

It is owing to the same inferiority in the cohesion of heterogeneous particles, that some of the compound supporters occasion combustion in circumstances when the combustibles would not be acted on by simple supporters.

Thus phosphorus burns in air at the common temperature; but it does not burn in oxygen gas, unless its temperature be raised.* In oxygenized muriatic acid gas, phosphorus burns rapidly at the common temperature of the air, and so do several of the metals; though they cannot be made to burn in air except at a very high temperature. Thus also oils burn rapidly when

* In the gaseous oxyd of nitrogen it requires a still higher temperature.

mixed with nitrous acid (p. 51). Nitrous gas and the gaseous oxyd of nitrogen constitute exceptions to this rule.

4. None of the *products* of combustion are combustible according to the definition of this process here given. This want of combustibility is not owing to their being saturated with oxygen; for several of them are capable of combining with an *additional dose* of it. But during this combination no caloric or light is ever emitted; and the compound formed differs essentially from a *product* of combustion; for by this additional dose of oxygen, the *product* is converted into a *supporter*. *Hence we see that combustion ought not to be confounded with the combination of a body with oxygen* as is generally done.

Combustion indeed cannot take place without the combination of oxygen; but oxygen may combine with bodies in different proportions without the phenomena of combustion; and the *product obtained* is capable of becoming converted into a *supporter* of *combustion*, for instance: If lead be melted, and kept so for some time, it becomes covered with a white pellicle, or white *oxyd of lead*, a product consisting of oxygen and lead; but if this white oxyd is suffered to be heated longer, it absorbs an additional quantity of oxygen, and becomes converted into a yellow powder, called yellow *oxyd of lead*. If this yellow oxyd be again exposed to heat, it absorbs still more oxygen, and becomes converted into *red oxyd of lead*. All these oxyds are therefore *supporters*. When the *supporters*, that formed by the combination of oxygen with *products*, are made to support combustion, they do not lose all their oxygen, but only the additional dose which constituted them supporters. Of course they are again reduced to their original state of products of combustion. Hence it follows, that they owe their properties as supporters, not to the *whole* of the oxygen which they contain, but to the *additional dose* which constituted them supporters. We may therefore call them *partial supporters*; indicating by the term, that part only of their oxygen is capable of supporting combustion, and not the whole.*

* Dr. Thomson supposes that it is very possible that both nitrogen and muriatic acid may be products of combustion; and in that case both the compound and partial supporters would agree with each other in every respect. In the present state of our knowledge, however, it is necessary to distinguish them.

All the partial supporters with which we are acquainted, contain a metallic basis; for metallic oxyds are the only products at present known capable of combining with an additional dose of oxygen. It is a circumstance highly deserving attention; that when metals are capable of combining with several doses of oxygen, the product or oxyd formed by combustion is seldom or never that which contains a *maximum* of oxygen.

Thus it is evident that several of the products of combustion are capable of combining with oxygen. *The incombustibility of products, therefore, is not owing to their want of affinity for oxygen*, but to some other cause.

5. No *product* of combustion is capable of *supporting* combustion. This is not occasioned by any want of affinity for combustible bodies; for several of them are capable of combining with an additional dose of their basis. But by this combination they *lose* their properties as products, and are converted into *combustibles*. The process therefore differs essentially from combustion. Thus sulphuric acid, a *product* of combustion, by combining with an additional dose of sulphur or its oxyd, is converted into *sulphureous acid*, a substance which, from several of its properties, the doctor concludes to be combustible. Thus also phosphoric acid, a product of combustion, is capable of combining with phosphorated hydrogen, and of forming *phosphorous* acid, a combustible body. When this last acid is heated in contact with a supporter, it undergoes combustion; but it is only the additional dose of the combustible which burns, and the whole is converted into phosphoric acid. Hence we see that it is not the whole basis of these compounds which is combustible, but merely the additional dose. The compounds, therefore, formed by the union of a product and combustible, may be termed *partial combustibles*; indicating by the name, that a part only of the base is capable of undergoing combustion. Since the products of combustion are capable of combining with oxygen, but never exhibit the phenomena of combustion except when they are in the state of partial combustibles, combustible bodies must contain a substance which they lose in burning, and to which they owe their combustibility; for after they have lost it, they unite to oxygen *without* exhibiting the phenomena of combustion.

Though the products of combustion are not capable of supporting combustion, they not unfrequently part with their oxygen just as supporters do, give it out to combustibles, and convert them into products; but during this process, no heat or light is ever evolved. Water, for instance, gives out its oxygen to iron, and converts it into *black oxyd*, a product, and sulphuric acid gives out its oxygen, to phosphorus, and converts it into phosphoric acid. Thus we see that the oxygen of products is capable of converting combustibles into products, just as the oxygen of supporters; but during the combination of the last only are heat and light emitted. The oxygen of supporters then contains something which the oxygen of products wants.

6. Whenever the whole of the oxygen is abstracted from products, the combustibility of their base is restored as completely as before combustion; but no substance is capable of abstracting the whole of the oxygen, except a *combustible* or a *partial combustible*. Water, for instance, is a product of combustion, whose base is hydrogen. To restore the combustibility of the hydrogen, we have only to mix water with iron or zinc filings and an acid; the metal is oxydated, and the hydrogen gas is evolved as combustible as ever. But no substance, except a combustible, is capable of separating hydrogen gas from water by combining with its oxygen. Thus we see that combustibles are capable of restoring the combustibility of the bases of products, but they themselves lose their combustibility by the process, and are converted into products. Combustibility, therefore, may be thrown at pleasure from one body to another.

From these facts it is obvious, that the products of combustion may be formed without combustion; but in these cases a new combustible is always evolved. The process is merely an interchange of combustibility; for the combustible is converted into a product only by means of a product. Both the oxygen and the base of the product having undergone combustion, have lost something which is essential to combustion. The process is merely a double decomposition. The product yields its oxygen to the combustible while at the same time the combustible gives out something to the base of the product; the combustibility of that base then is restored by the loss of its oxy-

gen, and by the restoration of something which it receives from the other combustible thus converted into a product.

There is indeed another method of forming the products of combustion, without actual combustion in certain cases; but the phenomena are much more complicated. This method is to expose them to the action of some of the supporters dissolved in water, especially nitric acid. Thus most of the metallic oxyds may be formed without combustion by the action of that acid on the metals. But in that case a new supporter is always evolved, namely, nitrous gas; ammonia, a new combustible, is also usually formed; and not unfrequently the *product* is converted into a *partial supporter*.

7. No *supporter* can be produced by combustion, or by any equivalent process. As all the supporters, except oxygen gas, consist of oxygen combined with a base, it follows as a consequence, that oxygen may combine with a base without losing that ingredient, which occasions combustion. The act of combination of oxygen with a base, therefore, is by no means the same with combustion. If we take a view of the different supporters, we shall find that all of them which can be obtained artificially are procured either from other supporters or by the agency of electricity.

I. Oxygen gas may be procured from nitric acid and oxygenated muriatic acid, two supporters; and from several of the partial supporters, as the black oxyd of manganese, the red oxyds of lead and of mercury. The action of heat is always necessary; but the process is very different from combustion.

II. Air, as far as is known at present, cannot be formed artificially. The gas, indeed, which comes over during part of the usual distillation of nitrate of potash and sulphuric acid to obtain nitrous acid, resembles air very closely. But it is obtained from a supporter.

III. The gaseous oxyd of nitrogen has hitherto been only procured from nitrous gas and nitric acid (nitrate of ammonia) both of which are supporters.

IV. Nitrous gas can only be procured by the decomposition of nitric acid, a supporter.

V. OXYGENIZED MURIATIC ACID can be formed by combining muriatic acid with the oxygen of the black oxyd of manganese, the red oxyds of lead, iron, mercury &c. all of which are partial supporters.

VI. NITRIC ACID is formed spontaneously upon the surface of the earth, by processes with which we are but imperfectly acquainted; but which certainly have no resemblance to combustion. Its oxygen is probably furnished by the *air*, which is a supporter: at least it has been observed, that nitrogen and oxygen at high temperatures are capable of forming nitric acid.

This formation of nitric acid by means of electricity has been considered as a combustion, but for what reason it is not easy to say; the substance acted upon is not a combustible with a supporter, but a supporter alone. Electricity is so far from being equivalent to combustion, that it sometimes in a manner acts diametrically opposite; *unburning*, if we may use the expression, a substance which has already undergone combustion, and converting a *product* into a *combustible* and a *supporter*. Thus it decomposes water, and converts it into oxygen and hydrogen gas; therefore it must be capable of supplying the substances which the oxygen and combustible lose when they combine by combustion, and form a product.*

8. Several of the supporters and partial supporters are capable of combining with combustibles, without undergoing decomposition, or exhibiting the phenomena of combustion. In this manner the yellow oxyd of gold and the white oxyd of silver combine with ammonia; the red oxyd of mercury with oxalic acid; and oxygenized muriatic acid with ammonia. Thus also nitrate of potash and oxygenated muriate of potash may be combined, or at least intimately mixed with several combustible bodies, as in gun-powder, fulminating powder, &c. In all these compounds, the oxygen of the supporter and the combustible retain the ingredients which render them susceptible of combustion; hence the compound is still combustible; and in consequence of the intimate combination of the component parts, the least alteration is apt to destroy the equilibrium which subsists between them; the consequence is, combustion

* The doctor does not mean to affirm that electricity never occasions combustion, the contrary of which is well known, but that a combination produced by it is not always the same with combustion.

and the formation of a new compound. Hence these compounds burn with amazing facility, not only when heated, but when triturated or struck smartly with a hammer. They have therefore received the name of *detonating* or *fulminating* bodies. Thus we have fulminating gold, fulminating silver, fulminating mercury, fulminating powder, &c.

9. Such are the properties of the combustibles, the supporters and the products: and such the phenomena which they exhibit when made to act upon each other.

If we compare together the *supporters* and the *products*, we shall find that they resemble each other in many respects. Both of them contain oxygen as an essential constituent part; both are capable of converting combustibles into products; and several of both combine with combustibles, and with additional doses of oxygen. But they differ from each other in their effects on combustibles. The former only produce combustion; whereas the products convert combustibles into products without combustion. Now, as the ultimate change produced upon combustibles by both these sets of bodies is the same, and as the substance which combines with the combustibles is in both cases the same, namely oxygen, we must conclude that this oxygen in the supporters contains something which the oxygen of the products wants, something which separates during the passage of the oxygen from the product to the combustible, and occasions the combustion, or emission of fire, which accompanies this passage. The oxygen of supporters then contains some ingredient which the oxygen of products wants. Many circumstances concur to render it probable that this ingredient is *caloric*.

The *combustibles* and the *products* also resemble each other. Both of them contain the same or a similar base; both frequently combine with combustibles, and likewise with oxygen; but they differ essentially in the phenomena which accompany their combination with oxygen. In the one case *fire is emitted*, in the other not. If we recollect that no substance but a combustible is capable of restoring combustibility to the base of a product, and that at its doing so it always loses its own combustibility; and if we recollect farther, that the base of a product does not exhibit the phenomena of combustion even when it combines with oxygen; we cannot avoid concluding, that all com-

bustibles contain an ingredient which they lose when converted into products, and that this loss contributes to the fire which makes its appearance during the conversion. Many circumstances contribute to render it probable that this ingredient is *light*.

If we suppose that the oxygen of the supporters contains caloric as an essential ingredient, and that light is a component part of all combustibles, the phenomena of combustion above enumerated, numerous and intricate as they are, admit of an easy and obvious explanation. The component parts of the oxygen of supporters are two; namely, 1. a base, 2. caloric: The component parts of combustibles are likewise two; namely, 1. a base, 2. light. During combustion the base of the oxygen combines with the base of the combustible, and forms the product; while at the same time the caloric of the oxygen combines with the light of the combustible, and the compound flies off in the form of fire. Thus combustion is a double decomposition; the oxygen and combustible divide themselves each into two portions, which combine in pairs; the one compound is the *product*, and the other the *fire*, which escapes.

Hence the reason that the oxygen of products is unfit for combustion. It wants its caloric. Hence the reason that combustion does not take place when oxygen combines with products or with the base of supporters. These bodies contain no light. The caloric of the oxygen of course is not separated, and no fire appears. And this oxygen still retaining its caloric, is capable of producing combustion whenever a body is presented which contains light, and whose base has an affinity for oxygen. Hence also the reason why a combustible alone can restore combustibility to the base of a product. In all such cases a double decomposition takes place. The oxygen of the product combines with the base of the combustible, while the light of the combustible combines with the base of the product.

But the application of this theory to all the different phenomena described above is so obvious, that it is needless to give any more examples. Let us rather inquire, with the author, into the evidences which can be brought forward in its support.

10. As caloric and light are always emitted during combustion, it follows that they must have previously existed, in the combustible, the supporter, or in both.

That the oxygen of the supporters contains either one or both of these substances, follows incontrovertibly from a fact already mentioned, namely, that the oxygen of products will not support combustion, while that of supporters will. Hence the oxygen of supporters must contain something which the oxygen of the products wants, and this something must be caloric or light, or both.

That the oxygen of some of the supporters at least contains caloric as an ingredient, has been proved in a satisfactory manner by the experiments of Crawford, Lavoisier, and La place. Thus the temperature of hot-blooded animals is maintained by the decomposition of *air*. Now if the oxygen of one supporter contains caloric, the same ingredient must exist in the oxygen of every supporter, because all of them are obviously in the same state. Hence we conclude that the oxygen of every supporter contains caloric as an essential ingredient.

The light emitted during combustion must either proceed from the combustible or the supporter. That it proceeds from the combustible must appear pretty obvious, if we recollect that the colour of the light emitted during combustion varies, and that this variation usually depends, not upon the supporter, but upon the combustible. Thus charcoal burns with a red flame, sulphur with a blue or violet, zinc, with a greenish white, phosphorus with a white flame, &c.

The formation of combustibles in plants obviously requires the presence and agency of light. The leaves of plants emit oxygen gas when exposed to the sun's rays, but never in the shade or in the dark.

Besides vegetation, we are acquainted with two other methods of *unburning* products, or of converting them into products and combustibles, by exposing them in certain circumstances, to the agency of *fire* or of *electricity*. The oxyds of lead, mercury, &c. when heated to redness, are decomposed, oxygen gas is emitted, and the pure metal remains behind. In this case the necessary caloric and light must be furnished by the fire; a circumstance which explains why such reductions always require a red heat. When carbonic acid is made to pass repeatedly

over red-hot charcoal, it combines with a portion of charcoal, and is converted into gaseous oxyd of carbon. If this gas be a combustible oxyd, the base of the carbonic acid and its oxygen must have been supplied with light and caloric from the fire; but if it be a *partial combustible*, it is merely a compound of carbonic acid and charcoal: which of the two it is, remains still to be ascertained.

Electricity decomposes water, and converts it into oxygen gas and hydrogen gas; it must therefore supply the heat and the light which these bodies lost when converted into a product.

These facts, together with the exact correspondence of the theory given above with the phenomena of combustion, render it so probable, that Dr. Thomson has ventured to propose it as an additional step towards a full explanation of the theory of combustion. Every additional experiment has served to confirm it more and more. It even throws light upon the curious experiments of the accension of metals with sulphur, which succeed, as stated already, *in vacuo*, under mercury, in nitrogen gas, &c.

Dr. Thomson has noticed that the same emission of caloric and light, or of *fire*, takes place when melted sulphur is made to combine with potash, or with lime, in a crucible or glass tube, and likewise when melted phosphorus is made to combine with lime heated to redness. He supposes that in all probability barytes and strontia exhibit the same phenomenon when combined with melted sulphur or phosphorus; and perhaps some of the metals when combined with phosphorus.

The phenomena Dr. Thomson explains thus: The sulphur and phosphorus are in a melted state, and therefore contain caloric as an ingredient; the alkalies, earths, and metals which produce the phenomenon in question, contain light as an essential ingredient. The sulphur or phosphorus combines with the metal, earth, or alkali; while at the same time the *caloric*, to which the sulphur or phosphorus owed its fluidity, combines with the *light* of the metal, earth, or alkali; and the compound flies off under the form of *fire*.

Thus the process is exactly the same with combustion, excepting as far as regards the product. The melted sulphur or phosphorus acts the part of the *supporter*, while

the metal, earth, or alkali, occupies the place of the *combustible*. The first furnishes caloric, the second light, while the base of each combines together. Hence we see that the base of sulphurets and phosphurets resembles the base of products in being destitute of light, the formation of these bodies exhibiting the separation of fire like *combustion;* but the product differing from a product of combustion in being destitute of oxygen, Dr. Thomson distinguishes the process by the title of *semi-combustion;* indicating by the term, that it possesses one half of the characteristic marks of combustion, but is destitute of the other half.

The only part of this theory which requires proof is, that light is a component part of the earths and alkalies. But as potash and lime are the only bodies of that nature which we are certain to be capable of exhibiting the phenomena of semi-combustion, the proofs must of necessity be confined to them. That *lime* contains light as a component part has been long known. Meyer and Pelletier observed long ago, that when water is poured upon lime, not only heat but light is emitted. Light is emitted also abundantly when sulphuric acid is poured upon magnesia, or upon lime, potash, or soda, freed from the water of crystallization. In all these cases a *semi-combustion* takes place. The water and the acid being solidified give out *caloric*, while the lime or potash gives out *light*.

That lime during its burning combines with light, and that light is a component part of lime, is demonstrated by the following experiment, for which we are indebted to Scheele.

It has been mentioned already that fluor spar (fluate of lime) has the property of phosphorescing strongly when heated, but the experiment does not succeed twice with the same specimen. After it has been once heated sufficiently, no subsequent heat will cause it to phosphoresce. Now phosphorescence is merely the emission of light; light of course is a component part of fluor spar, and heat has the property of separating it. But the phosphorescing quality of the spar may be again recovered to it, or which is the same thing, the light which the spar had lost may be restored by the following process:

Decompose the fluate of lime by sulphuric acid, and preserve the fluoric acid separate. Boil the sulphate of lime thus formed with a sufficient quantity of carbonate of soda; a double decomposition takes place; sulphate of soda remains in solution; and carbonate of lime precipitates. Ignite this precipitate in a crucible till it is reduced to lime, and combine it with the fluoric acid to which it was formerly united. The fluor spar thus regenerated phosphoresces as at first. Hence the lime during its ignition must have combined with light.

That potash contains light, may be proved in the same manner as the existence of that body in lime. Now as potash is deprived of its carbonic acid by lime, the doctor supposes that the process must be a double decomposition; namely, that the base of the lime combines with carbonic acid, while its light combines with the potash.

These remarks on semi-combustion might easily be much enlarged upon. For it is obvious that whenever a liquid combines with a solid containing light, and the product is a solid body, something analogous to semi-combustion must take place. Hence the reason why water increases the violence of combustion when thrown sparingly into a common fire, &c.

Such is the theory of Dr. Thomson, against which a few objections have been advanced by an anonymous writer (Nicholson's Journal, July 1802, p. 206.) but there is little doubt that these objections will soon be reconciled, when the ingenious investigations of Dr. Thomson have been the subject of further consideration.

END OF VOLUME I.

APPENDIX.

PAGE 11. NO. 1.

Stahlean Theory. It is necessary to explain what is the Stahlean Theory; according to which, there is only one substance in nature capable of being burnt or inflamed. Combustion therefore according to Stahl, consisted in the disunion of this principle of inflammability called by him PHLOGISTON, from the inflammable body: during combustion the phlogiston combines with heat, and is exhibited when so combined in the form of fire or flame: when all the phlogiston is disunited from the inflammable body, this latter is no longer inflammable. According to this theory, metals are peculiar earths united chemically to phlogiston; when by exposure to strong heat in the open air, or by solution in acids the phlogiston is separated, the metals lose their metallic properties, and become calcined; the term *calx*, or metallic calx, meaning under that theory, what *oxyd* means now. Those metals which would not part with their phlogiston by calcination in the open air, such as gold and silver, and whose calces could regain it without the addition of inflammable matter, were the *perfect* metals: the rest were called *imperfect* metals. When by means of heat, the uninflammable calx of a metal was treated with any inflammable substance, as charcoal, the phlogiston of the charcoal left the charcoal, and united with the metallic earth or calx: in this case, the charcoal became an incombustible substance, and the metallic earth was *reduced* (i. e. brought back to a metalline state) or *revived*; and again acquired the property of being combustible.

So when sulphur was burnt in open air, it became converted into the sulphuric or vitriolic acid (so called because this acid used formerly to be procured from green vitriol.) Here then, the phlogiston of the sulphur being burnt away, the sulphur became an incombustible acid. When this acid was treated with phlogistic or inflammable substances, it became sulphur again, as when sulphate of soda was fused with charcoal in a strong heat. So when the combination of potash and sulphur called liver of sulphur, was exposed to heat in open air, the produce was sulphate of potash. The inference seemed clear that combustion consisted in nothing more than the separation, by means of heat, of phlogiston, or the one common principle of inflammability, from the bodies with which it was united; that bodies united with or containing phlogiston, as wood, wax, oils, resins, charcoal, coal, &c. were combustible and inflammable, in consequence of this union alone; and when disunited were no longer so.

But John Rey, a French chemist, had noticed that metallic earths or calces *acquired weight* during their calcination; and Lavoisier by a train of most ingenious experiments, showed that the weight thus acquired was owing to the oxygen or pure part of atmospheric air imbibed during the process of calcination [oxydation.] That sulphur, also, on being burnt, absorbed and combined with, the oxygen of the atmosphere, and an acid was produced heavier than the sulphur employed, by the whole weight of pure or oxygen air which the atmospheric air had lost during the process.

Stahl's theory, therefore, could not be true, which explained combustion by means of the *loss* of one of the principles of the inflamed body; for instead of gaining in weight, it ought, according to that theory, to lose in weight. Kirwan, Keir, and Priestley long opposed this reasoning. Phlogiston, they said, was the inflammable air (hydrogen as it is now called) which was separated from metals during their solution in acids, and which formed a part of all combustible bodies. Still the accession of weight, where there ought to be a loss of weight, was not accounted for.

The French chemists then went further, and showed that the inflammable air came from the water, and neither from the metal nor the acid. They decomposed water into inflammable air and pure air, (hydrogen and oxygen) they composed water, by burning together, gradually, streams of hydrogen and oxygen: they showed that sulphur and oxygen formed sulphuric acid; that metals and oxygen formed metallic earths, calces or oxyds. They showed that when the oxygen was driven off, the metal was revived, without the addition of any principle of inflammability for the purpose. For the Stahlean Theory therefore, which made combustion to consist in the extrication of phlogiston by means of heat, they substituted the Lavoiserian or French Theory, which makes it to consist in the union of oxygen to an inflammable body. That theory has long reigned triumphant; but facts seem to indicate nevertheless, that there is such a substance as phlogiston, a principle of inflammability common to all bodies capable of being inflamed; and when united to caloric, forming hydrogen gas; and producing heat, and sometimes flame when it suddenly and violently unites to oxygen; and that combustion is nothing more than the union of oxygen and phlogiston, during which the latent heat of the two bodies thus combining, is set free; this heat is more violent in proportion to the quantity of the two substances combined, and the suddenness of their combination.

PAGE 31. NO. 2.

Dr. Hutton's Theory has been very ably defended and illustrated by Professor Playfair of Edinburgh: and Dr. James Hall in his papers on the Effects of Heat Modified by Compression (13 and 14 Nicholson's Journal) has shown that many appearances of carbonate of lime, which it was supposed nothing but watery solution could occasion, may be produced by heat, under a pressure which prevents the escape of the carbonic acid. His experiments also go far to show that the coal formations have probably been produced in the same way.

PAGE 39. NO. 3.

The facts hitherto observed, show, that all the transition and secondary mountains have at one time or other been covered with water; for the vegetable and animal remains found in them, can no otherwise be accounted for. But facts hitherto observed, do not show the same as to the granite and porphyry ridges which form the highest points of the highest mountains. There is no satisfactory evidence of any such remains being found in these primitive formations; which are so denominated and classed, from the fact of their containing no such remains.

PAGE 42. NO. 4.

Vegetables are fixed by the root, but they have loco-motion in their stem, branches, and leaves. The sun-flower has been observed to have its disk mostly turned to the sun. The hop winds round the pole in a similar direction. Let light be admitted, only through a hole, into an apartment, and a plant placed there will shoot in that direction. The roots of plants growing on walls, as house-leek, and of trees growing amid rocks, will turn out of their way to seek for nourishment, in joints and crevices. The contraction of the various species of mimosa or sensitive plant, of the dionœa muscipula, or Venus's fly-trap, of South Carolina, the hedasgrum gyrans—the bending of the stamina of the water-lily, to facilitate the process of impregnation, and many other facts collected by Dr. Percival, of Manchester, the bishop of Landaff, and Dr. Smith, of Litchfield, tend to make it rather probable than otherwise, that vegetables have the faculty of sensation, if not of voluntarity; and that the living vegetable, like the living animal fibre, is, in all cases, endowed with the property of contractility, on the application of appropriate stimuli.

PAGE 63. NO. 5.

The only two essential properties of matter are *extension* and *impenetrability*, frequently, though improperly, termed solidity; for the opposite to solidity, is fluidity.

These two properties of matter, are resolvable into the properties of attraction and repulsion, which appertain to every particle of matter at given distances; and as the planetary system has, so also has each particle of matter, centripetal and centrifugal forces. Matter is not inactive and inert, but is incessantly repelling or attracting other matter.

A few observations on this subject, not usually noticed in elementary books of chemistry or natural philosophy, may not be out of place.

Father Boscovick, in his Theoria Philosophiæ Naturalis, Mr. Mitchell, in the Philosophical Transactions, and Dr. Priestly, in his Treatise on Matter and Spirit, particularly the latter, have suggested that all matter may be permeable to other matter; and that mere physical points,

endowed with the properties of attraction and repulsion, are sufficient to account, in a general way, for all the phenomena of the material world. This opinion appears to be liable to an insuperable objection. Every property must be the property of *something*. A property is not conceivable, which is the property of nothing. In the character of relate and correlate, something is necessarily implied, as the subject to which a property or attribute is attached—in which it inheres—to which it belongs. If there be attraction and repulsion, there must be something which attracts and repels, which is attracted and repelled. This cannot be a mere ens rationis, a non-entity, a physical point. There are, therefore, primary atoms or molecules of matter, which, at certain distances, attract each other, and by means thereof, cohere and form an *extended* body. For if they were not connected by such a mutual attractive power, they would separate, and no extended body would appear. Hence, *extension*, depends on the attractive power belonging to each particle of matter, mutually exerted.

But at certain distances, each particle of matter, and each congeries of particles repel each other, that is, prevent any other particle or collection of particles, from occupying the same portion of space. I press my hand against a table, and I find it is resisted or repelled. This property is the property of repulsion, and gives rise to the other attribute or quality of matter, *impenetrability*.

That each particle of matter keeps each other at a distance, and that no two particles (atoms or molecules) are in absolute contact, appears probable from the following facts.

1st. All the great masses of matter, as the planetary system, require both attractive and repulsive powers (centripetal and centrifugal forces) to account for the phenomena they present.

2dly. The particles whereof all known bodies on the earth's surface are composed, can be brought nearer by cold, and removed farther from each other by heat, without solution of continuity. This is the foundation of all experiments with the thermometer and pyrometer. Thus, mercury and spirit of wine, expand in the glass tube, on the application of heat. If a polished cylinder of tin, which accurately fits a ring, be exposed to a boiling heat, it will no longer pass through the ring.

3dly. Sir Isaac Newton has shown that the particles of light are reflected and refracted before they come in actual contact with the body which produces this effect. See the third book of his optics, and the three first queries. So, a convex lens laid upon a polished glass, does not touch it by the 137th of an inch; a distance that can be diminished but not annihilated by great pressure.

4thly. Mr. Mitchell has shown, that a drop of water rolling on a cabbage leaf, is never in actual contact with the leaf.

5thly. A drop of oil poured upon water, is not in contact with the water whereon it rests.

6thly. Dr. Priestly has shown, that it requires considerable force to bring pieces of money, lying on top of one another, into sensible or apparent contact.

7thly. The electric spark is visible at every link of a suspended chain, forming part of an electrical circuit.

8thly. In all cases of crystallization, as the particles when crystallized, occupy (as in the case of ice) more room than before, the particles must be repelled, as well as attracted, in the direction necessary to form the crystal.

It has been supposed that all the various kinds of attraction and repulsion, are mere modifications of one and the same general property of the

ultimate particles, molecules or atoms of matter. They may be so, but in the present state of our knowledge, the attractions and repulsions of gravity (planetary) of cohesion, of chemistry, of electricity, of magnetism, of optical phenomena, of crystallization, appear so distinctly characterized as not yet to be resolvable, the one into the other.

Thus it appears, that although a state of inactivity, a vis inertiæ, an indifference to a state of motion or rest, may be predicated apparently of the masses of matter on the earth's surface; (which, however, according to the experiments of Dr. Maskelyn, on the attraction of the hill Schehallien, do nevertheless perpetually and mutually attract each other) yet as to all the more intimate and minute particles, of which bodies are composed, these are in a perpetual and active state of mutual attractions and repulsions, giving rise to the incessantly-continuing, never-ending decompositions and recompositions, to which all bodies on our earth, at least are manifestly subject.

Priestly, and some other philosophers, have supposed the ultimate particles of matter, to be surrounded by alternate spheres of attraction and repulsion. All this is mere conjecture. The most plausible, not to say probable hypothesis, to account for the apparent contradictory phenomena of attraction and repulsion, as appertaining to the ultimate molecules of matter, is that of Father Boscovick, in his *Theoria Philosophiæ Naturalis*. The curve he has assigned to illustrate the gradual increments and decrements of these forces, and their gradual receding into the character of each other, is so ingenious and so seemingly correspondent with the phenomena, that I cannot but recommend it to the attentive consideration of the student. Professor Robeson, of Edinburg, has given a good abstract of this theory, at the end of the article *Boscovick*, in the first volume of the supplement to Dobson's edition of the Edinburg Encyclopedia.

PAGE 66. NO. 6.

The weight which metallic wires, *one tenth of an inch* in diameter, will bear, is given by Accum so differently from the experiments of Count Sickengen, that I give the results of the latter. Iron, 705 lb. avoirdupois. Copper 387. Platina 351. Silver 239. Gold 191. In the 26th Vol. of Nich. Journ. 103, there is a paper by Guyton Morveau on the subject, by which it appears, that a wire of 2 millimetres, (787 of a line English) supported before it broke the following weights, in pounds avoirdupois.

Iron,	549.25 (549 1-4)	Gold,	150.753
Platina,	274.32	Zinc,	109.540
Copper	302.378	Tin	34.63
Silver,	187.137	Lead	12.371

PAGE 87. NO. 7.

Chemical affinity. Some additions may usefully be made to Accum's account of this subject.

The difference between the attraction of gravitation and chemical attraction, is, that the former acts on the mass, as a stone; the latter on the particles that compose the stone. The former acts at distances sensible, measurable: the latter only at insensible distances. Chemical affinity or attraction, differs from the attraction of cohesion or corpuscular attraction, in as much as the latter takes place between similar, the former only between dissimilar particles.

So in the attraction of magnetism the force exerted operates on the mass, and at considerable distances, which is not the case with the attraction of chemistry.

In the case of optical attraction, the forces operating on the rays of light, operate at a distance which can be made sensible, not so in the case of chemical attraction. The bodies that reflect or refract a ray of light do not alter its properties: the particles that operate on each other by chemical affinity, effect on each other a change of properties. In all cases of bodies united or disunited by the force of chemical attraction a change of properties, and a new and different body, is produced Of late Mr. Davy (now Sir Humphrey Davy) has brought forward experiments that tend strongly to prove an intimate connection at least, between Galvanic (Voltaic) electricity, and chemical affinity: but the facts do not afford satisfactory proof of perfect similarity. For, electricity acts at great distances, as we see in the cases of the common lightning-rod upon a jagged cloud—in the case of the electric spark and the electric shock, taken at a distance of an half an inch or an inch. Again: electricity passes along and through substances, combines with, and adheres to substances, without changing their properties; as through metals and probably glass; it forms an atmosphere round the conductor; it can be condensed by the condenser; it can combine with and even melt substances, as an iron rod, without changing any of their known chemical properties. Hence I must greatly hesitate before I can fully assent to the identity of the two forces.

The force of chemical affinity, is the same in the same particles, but different in different particles.

When two bodies are united chemically, the chemical attraction, which preserves their union, is termed *quiescent* affinity. When the same two bodies are disunited, by means of a third or a fourth, the chemical attraction which operates their disunion, is termed *divellent* affinity. When the sum of the divellent affinities, exceeds that of the quiescent affinities, disunion takes place. Thus, if sulphuric acid and soda, unite with a force equal to 4, to form Glauber's salt, and muriatic acid and lime, unite with a force also equal to 4, to form muriate of lime, the quiescent affinities will be expressed by the number 8. But if sulphuric acid and lime unite with a force equal to 5, and muriatic acid and soda, also with a force equal to 5, then the divellent affinities are the strongest by 2, and disunion takes place. The sulphuric acid and lime form gypsum, and the muriatic acid and soda, form common salt. This play of affinities is true, as a general rule, but it is liable to be counteracted by the insolubility of the substances, which may require solution or trituration, to overcome the force of cohesion; and by the want of heat or caloric, to assist in separating their parts.

Glauber's	Sulph. ac.	4	Soda	Salt
Muriat of	Muriat ac.		Lime	Lime
Sulphate of	Sulph. ac.	5	Lime	Lime
Muriat of	Muriat ac.		Soda	Soda

According to this diagram, when muriate of lime and Glauber's salt are mixed together in solution, gypsum will fall down and the supernatant liquor will contain common salt or muriate of soda.

Accum has mentioned Berthollet's discovery, that chemical affinity is not always invariable and exclusive in its action, but may be greatly modified. 1st, by the proportions, in the masses of matter, presented for decomposition; thus, though A may have a stronger affinity for B, than C has, yet the quantity of C may prevent the exclusive union of A with B; so an equal part of litharge will not decompose common salt, but if 5 or 6 times the weight of litharge be used, disunion will take place between the muriatic acid and the soda. 2dly, by the circumstance, that a body fully saturated with another, as manganese with oxygen, or potash with carbonic acid, is more easily decomposed than a body which is not saturated. Thus, you cannot, by heat, expel the last portions of oxygen from manganese; and when crystallized carbonate of potash, saturated with carbonic acid, is exposed to red heat, you can do no more than get the common or sub-carbonate of potash; you do not, by heat, get the potash quite free. The last portions of acid are always obstinately retained. 3dly, by the attractions of gravitation and cohesion, by defect of temperature, by elasticity, and in a case or two, (as in a paste of lime and common salt) by the efflorescence of one of the substances protecting the mass underneath. Berthollet, 4thly, states, that the chemical attractions of a compound, are no more than the sum of the chemical attractions of its component parts, modified as above, in law 3d, a position which is not, in my opinion, fully made out; for it is possible that new attractions may arise from the alteration in the shape and magnitude of the particles, composing the compound: and the attraction which governs crystallization, appears to me a pregnant instance of this. The other parts of Berthollet's theory seem well supported by undeniable facts.

But this system of the laws of chemical attraction or affinity, advanced by Berthollet, is not in full accord with another, that promises to become more fashionable, though not yet supported by proofs from induction, sufficiently numerous and accurate.

It had long been known and observed, that while certain bodies (as the mineral acids and alcohol with water) combine in any proportion, certain other bodies seem to combine only in definite proportions. Thus, a given quantity of water, will take up only a given quantity of salt: a given quantity of alkali, will combine with a given quantity of acid, and no more, so that in salts, perfectly neutral, the quantities of the base and of the acid, are at all times combined in one and the same proportion. In like manner, though oxygen will combine with metals, it does not appear that it will combine with them in any, but only in certain proportions. Sometimes a metal will combine with one quantity of oxygen, forming what is called a *protoxyd*, sometimes also with a larger portion, a *deutoxyd*; sometimes with a still larger dose, a *tritoxyd*, the highest portion of oxygen, combined with the metal, forming a maximum, or *peroxyd*. But although the metal will combine with any of these proportions, when circumstances are favourable to the combination, it is supposed or assumed, that it will never combine with any intermediate quantity. Thus if the protoxyd be composed of oxygen=4, and the deutoxyd of oxygen=8, the metal is not found combined with the proportions, 5, 6 or 7. Lead is an instance of a metal combining with four doses, the ash-coloured, the yellow, the red and the puce-coloured oxyd. Water is the only combination yet known of oxygen and hydrogen only; and they combine but in one proportion, to wit, 85 and 15.

The question is, whether this tendency, to combine in definite proportions only, is a law of chemical affinity, and how far it extends.

In the year 1789, Dr. Bryan Higgins, a lecturer of chemistry, in London, advanced the opinion, that bodies combine either one particle with one, one particle with two, or with three or more. About the year 1802, Mr. Dalton, of Manchester, adopted a similar hypothesis, which it is necessary to give some account of, as it has been adopted also, with few modifications, by Gay Lussac and Thenard, by Dr. Wollaston and by Sir Humphrey Davy; and has been opposed by Mr. Murray, lecturer in chemistry, at Edinburgh, and by Dr. Bostock, of Liverpool.

It must be remarked, that (in my opinion as yet) Mr. Dalton's notions do not amount to a *theory*, accounting for discovered facts, but to an *hypothesis* only, to be supported by facts yet remaining to be discovered.

Mr. Dalton, in his Chemical Philosophy, assumes certain postulata. 1st. That when bodies combine chemically, they unite in determinate proportions. 2dly. That when two bodies unite in one proportion only, it is reasonable to believe that they unite particle to particle, and then the combination is binary. 3dly. When bodies unite in two proportions, they must be presumed to be binary and ternary. When in three proportions, we may expect one to be binary, and the other two ternary. When in four, we may expect one binary, two ternary and one quaternary, this being (a priori) their most probable mode of union.

The following Table will exemplify Mr. Dalton's notions in this respect.

1 atom of A + 1 atom of B = 1 atom of C, a binary compound.
1 atom of A + 2 atoms of B = 1 atom of D, a ternary compound.
2 atoms of A + 1 atom of B = 1 atom of E, a ternary compound.
1 atom of A + 3 atoms of B = 1 atom of F, a quaternary compound.
3 atoms of A + 1 atom of B = 1 atom of G, a quaternary compound.

This system is adopted by Dalton, Wollaston and Davy. Gay Lussac applies it also to the phenomena of gases in particular, which he thinks (and indeed renders it probable) unite in proportions, dependent upon their quantities. Mr. Dalton's expression of this, his hypothesis, theory or system, is, "that in all cases the simple elements of bodies are "disposed to unite atom to atom singly; or if either is in excess, it ex- "ceeds by a ratio to be expressed by some simple multiple of the num- "ber of its atoms."

In conformity to this, Davy says, "It would be easy to bring forward "a great collection of evidence to show, that in all compound gaseous "bodies, the quantities of the elements are uniform for each species; "and that when two gaseous elements combine in more than one pro- "portion, that the second or third proportion is always either a multi- "ple or a divisor of the first; and the case seems to be analogous with "respect to all true chemical compounds, whether solids or fluids, in "which no mechanical mixtures can be suspected, and where no par- "tial decompositions can have taken place." For this collection of evidence, the student is referred (after a careful perusal of Berthollet's tract on chemical affinity) to Dalton's new Chemical Philosophy, and to Davy's Elements of Chemical Philosophy, wherein all the striking and prominent facts of induction are brought forward.

This is a very important view of the doctrine of chemical attraction; and if well founded, promises to afford results and inferences of great utility. For instance, it enables us to arrive at the relative weights of the atoms, or ultimate particles, whether of a simple or a compound body. Suppose (which is very nearly, but so far as depends on experi-

ment, not accurately true) that oxygen and hydrogen combine together to form water, in the proportion of 85 oxygen, 15 hydrogen, by weight. As this is the only proportion in which they are certainly known to unite, it is presumable that one particle of oxygen combines with one particle of hydrogen. The weight of oxygen then, is to hydrogen, as 85 to 15, or 5.5 to 1. Again, ammonia appears to be a compound of 80 nitrogen or azote, to 20 hydrogen; therefore, the weight of an atom of nitrogen is 4 times that of hydrogen, and nitrogen and oxygen are to each other, respectively, as 5.5 to 4. It is true that the specific gravity of hydrogen gas, is to oxygen gas, as about 1 to 15, but these gases consist of bases united to caloric, and the preceding calculations may perhaps, apply to those bases.*

This very neat and plausible aspect of chemical affinity, is opposed by Dr. Bostock and by Mr. Murray, on considerations whereof the following is a brief summary, drawn up from their examinations of Dalton's hypothesis.

1st. It is as probable, a priori, that a compound never found but in one proportion, as hydrogen and oxygen, may be a ternary or a quaternary combination, as a binary one. Why must it be taken for granted, that only one atom of hydrogen unites to one atom of oxygen, to form water? For aught we know, water may consist of two or three atoms of one united to one atom of the other. This objection holds still more strongly as to the ternary, quaternary and more complicated combinations. Hence the very foundation of the whole system is gratuitous; for on this supposition, all the computations rest.

2ndly. Because we have hitherto produced no other than one combination of hydrogen with oxygen, it does not follow that no other can exist. So far from it, that in the second part of his system, Dalton endeavours to show that the fluoric, muriatic and oxymuriatic acids, are compounds of hydrogen and oxygen, and computes the elementary atoms that enter into their composition.

3dly. When this theory is applied to facts, apparently established on unexceptionable authority among chemists, as to the various combinations of sulphur, carbon and nitrogen with oxygen, the numbers resulting from the theory, do not coincide with the facts, as Dr. Bostock has shown at length. (28 Nichols. Journ. 288.)

4thly. Suppose with Mr. Dalton, that water contains 7 parts of hydrogen, and one of oxygen, then either one atom of oxygen is seven times heavier than one of hydrogen, or there are seven times as many atoms of the latter, as there are of oxygen. May not either of these alternatives be assumed? a priori, the one is just as probable as the other; nor has Mr. Dalton assigned any reason for the preference he gives to his own assumption, except that it is more agreeable to the simplicity of nature, about which we know nothing. These are the substance of Dr. Bostock's objections.

To these Mr. Murray adds,

5thly. Berthollet has established, that bodies act chemically, not only in the ratio of their affinity, but of their affinity and quantity. With this law, Dalton's hypothesis cannot be reconciled. For if combination

* I suspect a mistake in all Davy's calculations of numbers, to express substances (Chem. Phil. 112.) arising from this source. When two measures of hydrogen gas are burnt, with one measure of oxygen gas, water is formed; but the bases of these gases unite with a part of their caloric only. That portion which is necessary to enable a fluid to become a gas, escapes.

takes place between two bodies in determinate proportions, if one atom of A is disposed to combine directly with one atom of B, there can be no accession of force by the application of ever so many atoms of B. While, if it be true, that bodies act in the ratio of their affinity and quantity, it appears to follow that their power of combination, unless arrested by external circumstances, must be unlimited, for the action of any number of particles of the one body, may be extended to one particle of the other.

6thly. The coincidences between the chemical facts and the theory, are not yet sufficiently *numerous* to afford ground for an induction so important. They are frequently nothing more than *approximations* to evidence in support of this theory, as in the case of the proportions that form water. The present state of chemical analysis, is not sufficiently *accurate and scientific*, to enable us to rely implicitly on assigned proportions. In many cases, the chemical authorities for the facts adduced, *do not precisely coincide*, and the facts are strained into a coincidence with the theory. In other cases, it may fairly be presumed, at least as yet, that the facts which do coincide with the hypothesis, may amount to no more than accidental coincidences.

7thly. I would add, that in all cases of chemical combination, the effects of caloric evolved or absorbed, is never taken into consideration by the gentlemen who argue on either side; whereas it should seem a circumstance of great moment to the calculation, particularly in the case of the formation, or the union of gases.

8thly. Nor do I find that the numbers, from calculation, come out in perfect coincidence with the numbers deduced from experiment. Oxygen gas is to hydrogen gas, according to the late experiments of Biot and Arago, as 1.10359 to 0.07321, atmospheric air being 1, upwards of 15 times heavier. But, if according to Dalton, combinations found only in one proportion, are presumed to unite atom to atom, then oxygen is to hydrogen only as 5.5 to 1, taking the composition of water for the standard. Nitrogen is to hydrogen, by Biot and Arago, as .969 to 1.10359, or as 4 to 4.45 nearly; but by the calculations of Dalton, the numbers ought to be as 4 to 5.5 nearly. I do not see at present how to reconcile the calculations of the hypothesis with matter of fact.

9thly. Atom is supposed to combine with atom. Of the ultimate atoms of matter, we know nothing. We do not know whether they be of the same size or the same shape; whether spheres, cubes, cones, pyramids, parallelopipeds, or any other configuration. There is nothing in the whole compass of physical knowledge, that will enable us to judge in what proportions they will unite. We are absolutely in the dark.

I consider, therefore, this hypothesis of Dalton and his followers, as true only in the cases where precise and accurate experiment frequently repeated, shows that it is true.* Many experiments show a close approximation to the law of multiple-combination, very few indeed are precisely coincident; certainly far too few as yet, to found a valid argument from induction. Even supposing the doctrine of multiple-combination to be true, I do not find it yet settled, whether it relates in all cases to weight or to bulk.

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* For instance, even in the fundamental experiment, the composition of water, Murray says that "the most exact experiments he ever made, gave 1.97 hydrogen in bulk to 1. of oxygen." (Supplement to his second edition, p. 10.)

Some modification and compromise, appears to have been proposed by Berthollet and Gay Lussac. But Sir Humphrey Davy, in his late work, considers Dalton's position as a law of affinity sufficiently established; wherein he appears to me premature, so far as respects the present state of knowledge.

In speaking of the laws of chemical affinity, some notice ought to be taken of its connection with voltaic electricity, so very splendidly discovered and illustrated by Sir Humphrey Davy. But as he has given a summary of the facts, which I can neither abridge to advantage, or improve, in Vol. 1, of his elements of Chemical Philosophy, page 142, et seg. I must refer to a book which every chemical student will have to consult. My reasons for not adopting the laws of electricity, and those of chemistry, as identical, I have already given above. Future discoveries will probably show us the differences between common and voltaic electricity, and their still closer connection with chemical facts.

PAGE 88. NO. 8.

On Heat or Caloric. Accum's account of heat is tolerably well drawn up, but I do not recollect any compiler, who has yet given room enough to this most interesting subject. Murray, Thompson, Henry, all give dissertations of great value, but none of them complete. Accum's statement may answer the purpose of an elementary book, but it is a part of chemistry that requires to be studied under all the aspects it can be made to present.

I do not know where there is to be found, a summary of the arguments that may be urged as to the nature of heat; and I shall therefore copy, as an addition to Accum, a part of my own lecture on this head of inquiry.

On the nature of heat, whether it be a matter *sui generis*, the substance called caloric, or merely an effect of motion.

Lord Bacon, Sir Isaac Newton, Hooke and the generality of English philosophers, until about the year 1785, were of opinion that the sensation of heat was occasioned by some kind of motion, that was communicated to, and took place among the particles of the heated body, whether undulatory or vibratory. Of late, this opinion has also been advanced by Sir Humphrey Davy, who considers heat as synonimous with the power of repulsion, and that it is the immediate effect of motion. The statement of his opinions, and his reasons for them, may be found in the 1st Vol. of his Elements of Chemical Philosophy, 93—98.

Huygens and Euler, seem to have been of opinion that heat and light are fluid bodies, pervading all space, and intervening between the particles of all other solid and fluid bodies; but producing sensible effects, only when put in motion by some exciting cause, ab extra. Thus, light was supposed to be existent among all the bodies on our earth, and throughout our atmosphere, but put in motion only by the sun, or by heat, or some other cause producing the usual phenomena of light; an opinion that, for aught I know at present, may be true.

After the experiments of Scheele, Black, Wilche, Irvin and Crawford, the opinion that heat was a matter, *sui generis*, producing the effects we usually associate with that word, gained ground very fast, both on the continent of Europe and in England, until it became, as indeed it now is, the commonly received opinion. I will state briefly, after my

own manner, what appear to me the most prominent arguments on both sides, premising, however, that at present I have not found sufficient reason to adopt the sentiments of those, who consider heat as the mere effect of some peculiar motion of the particles of the heated body.

1st. Heat radiates from the surface of a rough or coloured body; it is refracted, it is reflected, it can be concentrated. These are properties not of a property, but of a body. I cannot see how *motion* as such can be radiated, reflected, refracted, concentrated by refraction. Something must be moved. If the heat proceed from an iron ball, as it may, it is not the *iron* that moves from the concave surface of a polished metal reflector, or through the transparent substance of a glass lens. It is not the *air*, for this cannot pervade the glass; and Scheele has proved that the velocity, even of radiant heat, is such, as to preclude the possibility of heating the air itself, during the short space of time in question. It is not the *light*, so far as we know, for the experiment succeeds far below sensible ignition. Yet it must be *something* that is thus moved. The thing moved cannot be motion, which itself cannot exist where there is nothing to be moved. Motion is a word only, expressing the state of existence, the affection or property of some thing or substance.

It may be replied, that *sound* is the mere effect of motion; that it is propagated in right lines; that it can be reflected, as from a wall or a sounding-board; that it can be condensed, as from a speaking-trumpet.

True, but in this case we know to a certainty, that it is the air which is moved, which strikes the tympanum of the human ear, and which, in a channel that confines it, is condensed. Sound then is produced, not by motion, but by something moved; and it is diminished as you approach a perfect vacuum.

2dly. By an experiment of count Rumford, it appears that heat is transmitted through a torricellian vacuum.

To this it is answered, that we have never been able to produce a perfect vacuum; that in the upper part of a barometer tube, there is always mercurial vapour. To which I can only reply, as in the following argument.

3dly. Place a thermometer under the receiver of an air-pump, exhaust it quickly, the mercury will fall considerably; but in a short time it will rise again to its former height. Now it is strange, that the motion propagated through the atmosphere, or through a space nearly exhausted of atmospheric air, should be equally capable of affecting the thermometer, and producing the phenomenon of heat!

This is a difficulty to which I can suggest no reply, on the theory of motion; for a manifest difference ought to arise in the time and manner of the heat being communicated through an atmosphere of common density, and the air of an exhausted receiver, or through the vacuum of a barometer, or the almost inappreciable vapour of mercury, which might be condensed by a moderate degree of cold. A vacuum can be made in an air-pump, sufficiently perfect to affect sound; but the transmission of heat, is not thus affected.

4thly. Heat gives volume; it increases the bulk of bodies.

To this it is answered, that the same effect must be produced by any motion communicated, that occasions the particles of a body, mutually to repel each other to a greater distance than before.

I reply, this is true; but the expansion is as permanent as the heat, and is therefore inconsistent with continuous vibrations, undulations or gyrations, all of which imply a motion not propagated continuously in a

right line, which would produce a solution of continuity in the body itself; but a motion backward and forward, whether in a horizontal, a vertical or a curved direction. All these imply, that the heat remaining the same, the expansion is momentaneously varying, which seems contrary to fact.

5thly. It does not appear that heat follows the usual laws of motion.

This is answered by asserting the contrary. 1 Davy 94, 95.

But every chemist knows that heat is propagated with much more difficulty downward than upward, as in the experiments of Thompson and Murray, in reply to count Rumford. Even Bacon, in his definition of heat, found it necessary to include "a slight tendency upwards," which is the subject also of popular observation, from the frequency of its occurrence. Nor is heat propagated equally, or in like manner to a ball of wood, or of charcoal, and to a ball of iron. In fact, I know of no one of the laws of motion, stated by mechanical philosophers, to which heat is obedient.

6thly. If heat be merely the result of motion, it must be the result in all cases of the same kind of motion, for there must be an uniformity of cause to produce an uniformity of effect. But heat is produced in, and communicated by solids of all kinds, by granite and by gold—fluids of all kinds, water, oil, alcohol, mercury, acids, alkalies, neutral solutions—gases of all kinds. Can the motion, communicated to and by these very different substances, be precisely the same? Yet the hypothesis of motion requires this.

I know not what answer can be made hereto; for no one has yet pretended to ascertain what manner or kind of motion it is, that produces heat; nor are there any two persons yet agreed upon it.

7thly. I well know that in chemical mixtures, motions frequently exist, which are not obvious to the senses, but which are known to exist from their effects; but when water is perfectly crystallized into ice, and so remains, what motion can be supposed in the particles of such a body? and yet heat is certainly combined with it. For not only is the temperature of ice very far above the zero of absolute heat, but ice itself can be cooled lower than the freezing point. When the particles of the fluid are thus enchained, and when the polarity of its crystallization remains, which any uniform internal motion would destroy, where is the intestine heat-producing motion to be sought for?

8thly. The phenomena of chemical combination, are so well, so satisfactorily, so conveniently accounted for, by the supposition of heat or caloric being a substance combinable with bodies, extricable from them, producing, like all other bodies, its own peculiar play of affinities, that no substituted hypothesis of unknown and undefinable motion, can at all supply its place.

If it be answered, that there are many phenomena, which the theory of caloric will not explain, I acknowledge it; but they are comparatively few, and we are not yet fully apprized of all the circumstances attending them, nor of all the laws of combination of caloric. I know of no theory that has not its difficulties: whichever be found ultimately true, we are bound by the fair rules of reasoning to adopt for the present, that theory which explains the greatest number of important facts.

9thly. I cannot see what answer can be made to Dr. Herschell's experiment of calorific, separate from colorific rays. Mr. Leslie's angry remarks, contain nothing to the purpose, especially after the repetition of Herschell's experiments by Sir Harry Englefield, and the similar ones of Dr. Wollaston.

These show completely, that there are rays accompanying the coloured rays of the solar spectrum, which are not coloured, and which eminently produce the phenomena of heat. If heat be motion, why should not the *colorific* be also *calorific* rays? For their velocity is equal; they are transmitted together; they accompany each other; they pass together through a lens; they are refracted and reflected together. The only difference seems to be, that the calorific rays, are under certain circumstances, more inclined to combine with bodies than the colorific; as when in the case of culinary heat, they are intercepted for a time by a pane of glass. But who can pretend to distinguish either between their species of motion, or their relative velocities, so as to say why the rays producing colour should produce no heat?

10thly. I object to the whole doctrine of heat, as produced merely by motion, that the adopters of it, whether Bacon, Newton, Hooke, Boyle, or Davy, make use of words to which none of them have had, or have presented any definite meaning.

I have already ventured to say, it is absurd to talk of motion where there is nothing moved. If heat be communicated to a body by means of motion, it must be by means of some body in motion.

I hold my hand at the distance of half a dozen feet from a good fire, in a room with a strong draught to the fire place. What is it heats my hand? The heated air? No; for the current of heated air, is not *to*, but *from* my hand. The light? No; for by means of a screen of glass, I can for a short time intercept the heat, while the light passes.

But if heat consist in motion, it must consist in some known kind of motion: for an unknown motion, is to us no motion at all. *De non apparentibus et non existentibus eadem est ratio.*

Is it a vibratory motion? What is vibratory motion? A motion backward and forward. This may be of a whole body, as of a pendulum, or the string of a harpsichord; or it may be of the particles of a body, not inducing solution of continuity. Which is it?

Is it undulatory motion? The impulses of the air producing sound, have been called vibrations, undulations, wave-like motions. Heat also has been ascribed to undulations. I can understand how a wave-like motion can take place in the air when sound is heard, by analogy to the waves of the sea; but I cannot conceive how a ball of iron can be put into wave-like motions, or how the heated iron, and the heated air, can each receive exactly the same kind of vibrations or undulations in which heat is said to consist.

Heat has also been supposed to consist in gyratory motion: but this is to me equally unintelligible.

Nor less so is the gratuitous hypothesis of Sir Humphrey Davy, that heat is attended with a motion of the particles round their own axes. Where does he find, or how does he exhibit, or by what arguments prove this? Which of these philosophers have clearly explained what they mean by vibrations, undulations, gyrations, or peri-axin revolutions? Or have even attempted to show, how these can produce heat; or producing it (for instance in my face) can give precisely the same species of motion to the skin, the flesh, the nervous papillæ, and the containing vessels with their fluids, which are found on the surface of my face?

In short, I know of no instance in the whole compass of scientific discussion, in which words have been used with so little precision as in this controversy. I know of no one among the advocates for heat consisting in motion, who does not seem perfectly unaware, that *abstract*

ideas are not entities or things, but words only---that a property is not a substance; and that as there cannot be softness if there be nothing soft, or whiteness if there be nothing white, so there can be no motion but where there is something moved.

But I acknowledge, there are facts which I cannot explain, and which have not been explained satisfactorily to my apprehension, on the theory to which I incline.

When fire is elicited from flint and steel: when a piece of iron is hammered red hot;* when 26 1-2 lb. of water is made to boil by the friction of brass and steel immersed in the water itself, as in Count Rumford's experiment; when a piece of platina can be kept in strong ignition for an indefinite time, by the Voltaic apparatus; when a thermometer falls by the real or the seeming radiation of cold, I cannot account for the fact, on the theory of the materiality of caloric, any more than on the theory of motion.

I know, that in the first set of these cases, the apparatus used, is immersed in an atmosphere full of caloric, according to the common notion; but how that caloric is elicited so strongly and continuedly, by the means used, I know not. The radiation of cold, Dr. Martin seems to have explained (20 Nicholson's Journal, 342) but not in a manner so obvious as to remove all doubt. In these cases, I am ready to confess my ignorance of the modus operandi, whether on the theory I adopt, or the theory I reject. Rousseau truly says, a philosopher has frequent occasion to say *J'ignore*, seldom indeed to say, *c'est impossible*. Upon the whole, I incline to the common opinion of the materiality of heat, or caloric.

PAGE 137. NO. 9.

Light. The article Light in Accum, is well drawn up for an elementary treatise. Perhaps the following observations may be considered as an useful addition.

The sensation of light, is owing to impressions made on the optic nerve, expanded upon the retina at the back part of the eye. The light passes through three lenses, the aqueous, the crystalline, and the vitreous; and the impression remains according to D'Arcet's experiment one 400th to one 450th part of a minute. He made a luminous point (a hot coal) revolve with that velocity which was barely sufficient to produce a continuous circular image, which he found could not be done unless it revolved in 8 or 9 thirds of a minute. Hence it follows upon calculation, founded on the known velocity of Light, that its particles may be 20,000 miles distant from each other, and yet produce continuous vision. This experiment will go far to furnish a reply to the difficulties stated by Boscovick and Mitchell, arising from the probable impinging of the particles of light against each other. See on this subject Priestley's History of Optics, page 634. The sensations thus excited by the impression of reflected light on our retina, we are

* I am aware of Berthollet's experiments that show the heat of percussion to be dependant in some degree on the reduction of volume, but I cannot apply them to this fact. It seems to me that when iron is hammered so hot that you can light a match with it, the heat is squeezed out of the air, not out of the iron.

instinctively led to refer to some object extraneous to us as the cause. Hence however, Bishop Berkely and his followers, have been led to advance that the material world, is only a Theory to account for our sensations. But it is a theory founded on the constitution of the human frame.

Light may be considered, 1st, as solar light. 2dly, as artificial or culinary light. 3dly, as light arising from chemical mixture. 4thly, as phosphorescent light. 5thly, as electrical light. 6thly, as light excited under circumstances dependant on physiology. 7thly, as reflected light from the moon and stars. *Solar Light.* Does it proceed from the sun? Or is it a fluid occupying space, and put in motion by the objects that occasion the sensation? The latter opinion is supported by Malbranche, Huygens, Le Cat, Euler, Franklin, Higgins, Dr. T. Young: who support it by the difficulties that flow from supposing that light projected from the sun and the stars continually, never impinges against light, or is moved out of its rectilinear motion—that it can hardly be supposed to permeate the densest diaphanous bodies without impinging; that however small the particles, the constant emission of it in such inconceivable quantities, must cause waste; that every part of space, and all bodies absorbent of light, must long ago have been saturated with it; that if light be emitted continually from the luminous sources of it, it must exist, whether we see it or not; but if the luminous source be shut out from our eyes, as when we shut out the sun and the stars, the light seems to us annihilated; so when we suddenly extinguish a candle, we extinguish to our senses, instantaneously, not only the contiguous light, but all the light that has been emitted for a considerable time, visible in every part of a sphere of two miles in diameter, for a candle in a dark night is visible at 2 miles distant; that if the light of the sun pass a space equal to 93 millions of miles (the distance from the earth to the sun) in 8′ 13″ 3‴ (La Place) then the whole sphere whereof the sun is the center, will be filled with light in 8′ 13″ 3‴: but the emission of light goes on without end or intermission; hence light must be greatly concentrated in every part of the solar system: whereas we know that strong combustion takes place, when light is concentrated by means of a lens or a mirror one thousand times. How is it then, that our globe has not been melted?

How the properties of light can be satisfactorily accounted for, on the theory of this sensation being occasioned by the undulations of a fluid medium, existing in, and pervading the space intervening between the substances of our planetary system, Dr. Young has with great ingenuity attempted to show, in the second and subsequent volumes of Nicholson's Periodical Journal; and indeed in a manner that seems by no means inconsistent with the properties that Sir Isaac Newton himself was inclined to ascribe to his Æther.

The opinion that light is a substance sui generis, propagated from the luminous object in straight lines, was adopted by Boyle, Hooke, Sir Isaac Newton; and is now the commonly received opinion. The objection of Sir Isaac Newton, Opt. Qu. 28, to the theory of an undulatory medium, is principally, that when such an undulation is stopped in its progress by any object, the motion is communicated undiquaque to the surrounding quiescent medium, and will reach even beyond that obstacle. This is the case with water and air: but it is not so with light, which always moves in straight lines; and when impeded by reflection or refraction, forms not curves but angles. That light also does not undulate, appears from its never passing through a crooked tube, whereas the air, an undulatory fluid, will give the sensation of sound

through such a tube. Moreover the general phenomena of light, according to Sir Isaac Newton and his followers, seem much more accordant with the theory of particles thrown off in straight lines, than with the opposite doctrine. *Non nostri tantas est componere lites.*

The analysis of light by the prism into calorific and colorific rays by the experiments of Dr. Herschell, Dr. Wollaston, and Sir Harry Englefield, has already been noticed.

The solar spectrum, consisting of seven coloured rays, has been considered lately by Prieur, 17 Nich. Jour. 18. He considers the red, green, and violet as the primary rays, and that the others are composed of these. He obtained white light, by combining the red, green and blue rays.

Gay Lussac and Thenard, have ascertained that mixtures of oxymuriatic and hydrogen gas, which have little or no action on each other in the dark, act on each other when exposed even to a weak light, and may be made to explode by the direct rays of the sun. Mr. Dalton had observed the same fact.

Hence it appears that the white solar ray is divisible into seven different *colorific*, or colour-producing rays, the red, the orange, the yellow, the green, the blue, the indigo, the violet. Of these, some are primary, the others produced by intermixture: that these rays are also accompanied with *calorific* or heat-producing rays, which extend somewhat beyond the bounds of the coloured rays: there are also, as appears by the experiments of Dr. Herschell and Dr. Wollaston, another set of rays, which are *de-oxydizing* rays. These rays also extend somewhat beyond the bounds of the coloured rays, and are strongest on the outside of the violet ray, decreasing in de-oxydizing power as you recede from the violet toward the red ray; thus, muriate of silver undergoes a change in 15 seconds in the blue ray, which it requires 20 seconds to effect in the red ray. This de-oxydizing power, seems exerted in a contrary direction to the heating power, for the thermometer is affected less and less as you recede from the red ray toward the violet.

With respect to the solar rays it may further be observed in a chemical point of view, that from the experiments of Biot, and Arago, of which there is an abridgment in 26 Phil. Mag. 152, 292, it appears, that oxygen refracts least and hydrogen most at equal densities, a property that led Sir Isaac Newton to that wonderful suggestion, that water and the diamond were inflammable substances, from observing the uniform superiority of refracting power in substances of this kind. Hydrogen refracts 6 1-2 times more than common air. All strongly refracting substances appear to owe their refracting power to Hydrogen. Atmospheric air gives exactly by experiment, the refraction which according to calculation ought to be produced by a mixture of 787 nitrogen, 210 oxygen, and 3 carbon, which are nearly if not exactly, the component parts of common air. This rule holds in other compound mixtures: thus ammoniacal gas has a refractive power equal to that which nitrogen mixed with hydrogen would have, in the proportions that constitute ammonia. (Biot.)

With respect to artificial light, I know not of any experiments that decisively show its difference in property from solar light, particularly as to its power of promoting vegetable growth and colour, and its power of de-oxydation: in both respects however, there is no doubt of its general inferiority to the solar rays.

The light arising from chemical mixture, seems in all cases similar to artificial light, and produced by the sudden and violent union of heat, oxygen and hydrogen, but whether, the light be evolved as an effect of

chemical decomposition, or whether it be formed during the process, the present state of our knowledge does not permit us to decide.

Accum is sufficiently full on the subject of phosphorescent light, but it is a subject not yet understood. I do not think it is yet settled whether the ignis fatuus be carburetted hydrogen, or a fire flow: the phosphorescence of rotten wood, and of fish verging to putridity, *seems* the effect of very slow combustion: the phosphorescence of the sea consists apparently of animal matter; I have frequently collected it, by straining the illuminated water through a towel, but I could not discover that light on the towel, was owing to any minute living animal. Many plants also, or their pollen, are phosphorescent in July and August, as the marigold, monks-hood, the Indian pink, the orange, lilly, &c. at sunset.

Nor are we at all acquainted with electric light: at least I know of no facts that will authorise me to make a conjecture as to its immediate cause or its composition: that it is accompanied by heat is certain, as it will burn trees and houses, melt metals, and even the electric spark will fire gunpowder and spirit of wine. But whether hydrogen and oxygen are concerned in its production, or existence, or whence they are derived, we know not yet.

The light dependant on animal organization, is also involved in obscurity: when a man receives a blow on the head: when he is hung, without extinction of life; when he receives a blow on the eye, or strongly compresses the eye-ball; when he makes his eye a part of a Galvanic circuit by means of silver and zinc, in all these cases, and in many others he has the sensation of a flash of light.

The light of the glow-worm, and of the fire-fly seems voluntary, and dependant on the organs of the animal, who probably means the light in both cases as a signal to its mate. Something like the power of exciting the sensation of light, belongs also to cats and tygers, whose eyes do certainly under circumstances of irritation, shine in the dark.

The light of the moon seems unaccompanied with any calorific rays; indeed that planet, according to Bougier, does not reflect more than about 1-7th of the light it receives, and is about 300,000 times less than that of the sun. Concentrated in a lens, it does not affect the thermometer. It does not furnish an analysis like the solar spectrum: it does not appear to give colour to vegetables, or to produce de-oxydation.

PAGE 174. NO. 10.

Hydrogen Gas. I know of no proof whatever that hydrogen gas is formed of solid hydrogen, caloric, and light. That caloric enters into the composition of all the gases, is more than probable, but I know not any satisfactory evidence that light forms a part of this gas.

PAGE 198. NO. 11.

Phosphoric Bottle. Phosphorus and sulphur may be fused together in in a tube exhausted of air; the most inflammable and fluid mixture is one and a half sulphur to two phosphorus; which remains liquid, at 40 of Fahrenheit; but I have never been able to make these combinations

without so much hazard of explosion and fracture of the vessel, even in small quantities, that like the fulminating silver, a young chemist should not attempt it.

PAGE 211. N0. 12.

Differences between Charcoal and the Diamond. Charcoal is black, opaque, not weighty, nor crystallized, generally brittle or soft, is a residuum after distillation in close vessels of animal or vegetable matter, is a conductor of electricity. The diamond is brilliant, transparent, heavy, crystallized, harder than any other substance, has no connection so far as we know with animal or vegetable matter, is a nonconductor of electricity, Yet both are resolvable into carbonic acid gas with oxygen, producing from equal weights, hardly any difference in the quantity of gas or of residuum, so that according to chemical decomposition they are the same substance. Davy conjectures that there may be a very small quantity of oxygen in the diamond.

PAGE 217. N0. 13.

On the nature of the Gases. The following table exhibiting an arrangement of all the permanent gases hitherto known, is from 1 Henry's Chem. Edit. 6th, p. 175.

CLASS I. *Gases with simple Bases.*

Oxygen, Hydrogen, Nitrogen } Gas.

CLASS II. *Gases with compound Bases.*

1st. Compound combustible Gases.

Name	*Composed of*
1 Ammonia	Hydrogen and nitrogen.
2 Carburetted hydrogen	Hydrogen and carbon.
3 Olefiant gas	Carburetted hydrogen and carbon.
4 Sulphuretted hydrogen	Hydrogen and sulphur.
5 Phosphuretted hydrogen	Hydrogen and phosphorus.
6 Arsenuretted hydrogen	Hydrogen and arsenic.
7 Potassuretted hydrogen	Hydrogen and potassium.

2d. Oxyds in the state of Gas.

1 Carbonous oxyd	Carbon and oxygen.
2 Nitrous oxyd	Nitrogen and oxygen.
3 Nitric oxyd	Nitrous oxyd and oxygen.

3d. Acid Gases.

1 Carbonic acid	Carbon and oxygen.
2 Sulphurous acid	Sulphur and oxygen.
3 Nitrous acid	Nitric oxyd and oxygen.
4 Nitric acid	Nitrous acid and oxygen.
5 Muriatic acid	Unknown.
6 Oxymuriatic acid	Muriatic acid and oxygen?
7 Hyperoxymuriatic acid	Oxymuriatic acid and oxygen
8 Fluoric acid	Fluorium and oxygen.
9 Fluoboric acid	Fluoric and boracic acids.

Specific Gravities of the principal Gases from Gay Lussac.

Gases		*Determined by*
Atmospheric air	1.	Biot and Arrago.
Oxygen gas	1.10359	
Nitrogen gas	0.96913	
Hydrogen gas	0.07321	
Carbonic acid gas	1.5196	
Ammoniacal gas	0.59669	
Muriatic acid gas	1.278	Biot and Gay Lussac.
Nitrous oxyd gas	1.61414	Davy.
Do.	1.36293	Berthollet.
Nitric oxyd gas	1.0388	Berard.
Sulphurous acid gas	2.265	Kirwan.
Carbonic oxyd gas	0.9569	Cruikshanks.
Aqueous vapour	0.6896	Trales.
Oxymuriatic acid gas	2.470	Thenard and Gay Lussac.

Table of the elements of Elastic Fluids; with a view also to illustrate the Theory of multiple or definite proportions; by GAY LUSSAC.

Substances.	*Proportions in Volume.*		*Proportions in weight.*			
Muriate of ammonia	100 gas amm.	100 gas muriatic	Amm.	38.35	ac. mur.	61.65
Carbonate of ammonia	100 idem	100 g. carb.	idem	28.19	ac. carb.	71.81
Sub carb. of ammonia	100 idem	50 idem	idem	43.98	idem	56.02
Fluoborat of ammonia	100 idem	100 g. fluobor.				
Sub fluobor. of amm.	100 idem	50 oxyg.				
Water	100 gas hydr.	50 g. oxyg.	oxyg.	86.733	hydr.	13.267
Nitrous oxyd gas	100 nitrog.	50 oxyg.	nitrog.	63.72	oxyg.	36.28
Nitric oxyd gas	100 idem	100 idem	idem	46.757	idem	53.243
Nitrous acid	100 idem	200 idem	idem	30.512	idem	69.488
Nitric acid	200 nitrog.	100 g. oxyg.		idem		idem
Nitrous acid gas	300 idem	100 idem	idem	34.507	idem	65.493
Ammonia	100 nitrog-	300 hydrog.	idem	81.525	hydr.	18.475
Sulphuric acid	100 sulphuro. ac.	50 g. oxyg.	sulph.	42.016	oxyg.	57.984
Sulphurous acid			idem	52.083	idem	47.91
Oxymuriatic acid	300 gas mur.	100 oxyg.	ac. mur.	77.65	idem	22.35
100 carb. ac. gas	100 gas oxyd car.	50 g. oxyg.	carb.	27.376	idem	72.624
100 carb. ac. gas		100 oxyg.		idem		idem
100 carbonic oxyd	50 gas oxyg.		carb.	42.99	oxyg.	57.01

Similar Table; by DALTON.

Gaseous Substances.	*Per cent. by measure.*	*Per cent. by weight.*
Ammon. gas	52 nitrog. 133 hydr.	83 nitrog. 17 hydrog.
Water	100 oxyg. 200 hydr.	87 oxyg. 12.5 hydrog.
Nitrous gas	46 nitrog. 55 oxyg.	42 nitrog. 58 oxyg.
Nitrous oxyd	99 nitrog. 58 oxyg.	59 nitrog. 41 oxyg.
Nitric acid	180 nitr. gas 100 oxyg.	27 nitrog. 73 oxyg.
Nitrous acid	360 nitr. gas 100 oxyg.	33 nitrog. 67 oxyg.
Oxymur. acid	150 mur. ac. 50 oxyg.	76 mur. acid 24 oxyg.
Sulphurous acid	100 oxyg. sulphur	52 oxyg. 48 sulphur
Sulphuric acid	100 sulph'us ac. 50 oxyg.	79 1-2 sul. ac. 20 1-2 oxyg.
Carbon. oxyd	47 oxyg. charcoal	55 oxyg. 45 charcoal
Carbon. acid	100 oxyg. charcoal	72 oxyg. 28 charc.
Carburetted hydr.	200 hydr. 1 part char.	27 hydr. 73 charc.
Olefiant gas	200 hydr. 2 parts char.	15 hydr. 85 charc.
Sulph. hydrog.	100 hydr. sulphur	7 hydr. 93 sulphur
Muriate of ammon.	100 mur. ac. 100 am. gas	65 mur. acid 35 amm. gas
Carb. of Amm.	100 carb. ac. 80 am. gas	76 carb. acid 24 amm. gas
Sub carb. of amm.	100 carb. ac. 160 am. gas	61 carb. acid 39 amm. gas

It appears to me that notwithstanding the approximation of these two tables, the round numbers of Mr. Dalton's, furnish suspicion that they are to a certain degree forced into coincidence with the experiment.

It may be further observed generally as to gases, that their gaseous form is most probably owing to a combination with caloric, which in many instances may be shown, as when muriatic gas is made to combine with water.

The caloric may also be shown in many instances by sudden compression, as in the case of common air by means of the cylinder and piston used for lighting spunk or fungus (*Amadon.*)

It seems to be a law, that *the volume of a gas, is inversely as the compressing force.* Thus, if under the weight of one atmosphere a gas occu-

pies 60 cubic inches, it will occupy 30 under twice the weight and 15 under 4 times the weight. It is thus that the artificial Seltzer water is made; and that water is enabled to take up nearly its bulk of oxygen.

The *law of the dilatability of gases*, is about one 480th part of their bulk, for every degree of Fahrenheit's scale between the freezing and the boiling points of water.

It seems also to be a law respecting gases, that *a lighter cannot remain upon a heavier without admixture*. Thus provide two ounce phials, and a tube 10 inches long and about 1-20th of an inch bore. At each end the tube is to be passed through a perforated cork previously fitted to the phials. Fill one with oxygen and the other with hydrogen gas; cork the phial containing oxygen, and then cork the phial quickly which contains the hydrogen; let the oxygen phial, stand with its mouth up, and the phial containing hydrogen with its mouth down. In about 3 or 4 hours, each bottle will explode if a lighted taper be applied.

PAGE 218. NO. 14.

All gases are not incondensible by cold. Æther may by means of heat be exhibited in a gaseous state, but it may be condensed again. Oxymuriatic gas is condensible at 40° of Fahrenheit.

PAGE 225. NO. 15.

Methods of obtaining oxygen gas. Although this gas is procured more cheaply and conveniently from nitre and from manganese than any other way, it is worth while to mention, that it can be procured in great purity from mercurious precipitates per se, or mercury oxyded by heat in contact with air; and from hyperoxymuriate of potash. It can be procured from red lead, from the per oxyd or puce coloured (flea coloured) oxyd of lead: from red precipitate; either by means of heat alone, or by moistening the substances with colourless oil of vitriol a little diluted, and then applying heat.

PAGE 228. NO. 16.

Oxygen gas is absorbable by water. Dr. Henry has ascertained that at 60 of Fah. water takes up 1-27th of its bulk. Mr. Paul by compression makes water take up half its bulk.

PAGE 236. NO. 17.

Discovery of hydrogen gas. This gas was procured from a solution of iron in vitriolic acid by Mr. John Maud, in July 1736 (Martyn's Abrid.

Phil. Trans. v. 2. p. 396.) Before that, inflammable air or rather perhaps carburetted hydrogen, had been collected in a bladder, and exhibited before the Royal Society by Sir James Lowther, from his coal mines at Whitehaven.

PAGE 240. NO. 18.

Hydrogen gas. Although this gas be unfit for respiration in its pure state, it may be breathed when mixed with 3 or 4 times its volume of atmospheric air. Mr. Watt of Birmingham whose daughter died of consumption, told me, that she never breathed a mixture of hydrogen and common air, without manifest ease and an alleviation of all the symptoms; but I know of no case where the exhibition of the gases of any kind (I might almost say of any kind of medicine) has performed a cure in that disorder, the Opprobrium Medicorum. Still, the benefits of the gases in various disorders, as shown in the many successful cases of Dr. Thornton's practice, strongly points to their use.

PAGE 245. NO. 19.

Other properties of hydrogen gas. When this gas, issuing from a tube inserted in the cork of a phial containing oil of vitriol diluted with five waters, and iron filings, is set fire to, and the flame permitted to ascend through a glass tube of 18 or 20 inches long, whose upper end is drawn out to a capillary bore, a musical sound is produced. Care must be taken not to fire the hydrogen of the phial till all the common air is expelled by the hydrogen, else an explosion will take place. The sounds may be varied, by means of tubes of different sizes and dimensions. 1 Nich. Jour. 129 and 4 Nich. Jour. 23.

A mixture of hydrogen and oxygen gases may be made to explode by mechanical compression 12 Nich. Jour. 212.

Perhaps the strongest heat known, may be produced by the combustion of a stream of oxygen with a stream of hydrogen gas, issuing through the aperture of a blow pipe. Mr. Hare's ingenious contrivance for firing these gases may be found in the last volume of the American Philosophical Transactions: and the double gazometer, with separate partitions as improved by Mr. Cloud of the Mint of the United States, secures the operator from the danger of explosion.

When hydrogen and chlorine or oxymuriatic gas, in equal volumes, are mixed in a jar and left together exposed to day light, over mercury, common muriatic acid gas is formed. If exposed to the solar rays, they explode. One volume of hydrogen unites to one volume of chlorine, which is in weight to hydrogen as 33.5 to 1. Whereas about two volumes of hydrogen unite to one volume of oxygen to form water. It is doubtful as yet, whether the hydrogen unites to the oxygen supposed to be in the chlorine, and forms moisture, leaving the muriatic acid gas free from oxygen, or when chlorine and hydrogen form muriatic acid gas.

This mixture may also be exploded by the electric spark, as well as by the solar rays.

PAGE 248. NO. 20.

Nitrogen gas *is* absorbable by water in a small degree. By Dr. Henry's experiments, water takes up 1-75th of its bulk.

PAGE 250. NO. 21.

Other properties of nitrogen. It can be separated from ammoniacal gas, by decomposing this last by firing it with oxygen by means of the electric spark. It is procured also in the fine experiment of Dr. Milner of Cambridge, (Phil. Trans. 1789.) of decomposing ammonia by passing it through red hot manganese. The hydrogen of the ammonia forms water with part of the oxygen of the metal, and the nitrogen passes over also combined with oxygen so as to form nitrous gas. It has been supposed that this experiment has been employed by the French in making gun-powder.

PAGE 259. NO. 22.

Lavoisier's experiments. One of Lavoisier's experiments deserves to be mentioned. There used to be prepared by the druggists a brownish red oxyd of mercury called *precipitate per se.* Fluid mercury was exposed in a glass matrass with a long neck to prevent the evaporation of the mercury, to a continued heat for several days, until the mercury was calcined, or oxyded as we now call it. Lavoisier, made a quantity of precipitate per se, in a given quantity of atmospheric air. The air was diminished in quantity: it would no longer support flame or animal life. The mercury so converted into precipitate per se, had gained in weight. The air was expelled from it by heat in a retort: it amounted to the quantity absorbed. The mercury was revived; and this air so expelled, singularly maintained combustion. When added to the air diminished by calcination, an air similar to common air was produced. The weight gained by the mercury, was equal to the weight lost by the cemmon air. Hence precipitate per se, was shown to be fluid mercury united to that part of the atmosphere, which is alone capable of supporting life and combustion: and the atmosphere was shown to consist of two kinds of air or gases, of which one would support life and flame and would combine with mercury, and the other would not.

PAGE 268. NO. 23.

Eudiometer. Beside the eudiometers here enumerated it is worth while to notice Volta's, and the eudiometer of Messrs. Hope and Pepy's.

Volta's eudiometer is a graduated tube furnished with brass wire passing through the sides, so as to admit of the gases being fired. Three parts of common air may be fired with two parts of hydrogen gas

very pure. There will remain, if the airs be good, 3,05 measures. The loss will therefore be 1,95 measure, of which one third will be oxygen. If so, the oxygen in the common air will amount to 21 and a fraction per cent. "The general rule for ascertaining the purity of the air by hydrogen gas, may be stated as follows. Add to three measures of the air under examination, two measures of pure hydrogen gas. Inflame the mixture by electricity: observe the diminution when the vessel has cooled: and dividing its amount by 3, we obtain pretty nearly the quantity of oxygen gas which has been condensed." (Henry.)

The eudiometer of Dr. Hope, which is very simple and convenient, may be found in 4 Nicholson's Jour. 210. A long graduated tube is fixed in a phial containing liquid sulphuret of potash. This is inverted into the air intended to be examined, which may thus be repeatedly forced through the liquor that is to absorb the oxygen. This eudiometer like the improvement of Mr. Pepy's, 29 Phil. Magazine, consists in the apparatus rather than the principle, but they facilitate and give accuracy to the result.

PAGE 276. NO. 24.

Carbonic acid gas absorbable by water. This gas in the temperature of 41 Fahrenheit, unites to its own bulk of water. Absorption is greatly promoted by agitation and by pressure. Dr. Henry has determined that water takes up its own bulk of compressed or of uncompressed carbonic acid gas; and therefore that the quantity which water may be made to imbibe, is directly as the pressure. In the common machines for making seltzer water, the gas is strongly forced into the water by being pumped out of the reservoir where it is collected and forced into the water in a very strong copper vessel closed by a valve, by means of a condensing pump. Mr. Cloud of the Mint, has ascertained, that if a common keg or barrel be made perfectly air tight, strongly bound with wooden or iron hoops, having a shelf about two thirds of its height from the bottom, and filled nearly up to the shelf with water, this water may be very highly charged with carbonic acid gas by means of diluted vitriolic acid and chalk in sufficient quantity placed on the shelf in proper vessels. The head must fit very tight and be very strongly secured, otherwise it will be forced off. The gas is extricated very fast and being accumulated gives the necessary pressure by its own elasticity.

PAGE 302. NO. 25.

Sulphuretted hydrogen gas; other properties of it. It tarnishes metals: it reddens litmus paper: it destroys vegetable colours: it is gradually decomposed in a close bottle: it is transported with great difficulty: it is decomposed by means of the electric spark repeatedly passed through it: and by ignited charcoal. Davy conjectures it contains a small quantity of oxygen: potassium burns brilliantly in it. This gas impregnates very strongly indeed the water of a spring about 10 miles from Geneva in the Gennesse country. It abounds in the medicinal spring in York county, and in the spring of the same kind about five miles from Carlisle in Pennsylvania.

PAGE 324. NO. 26.

Gaseous oxyd of nitrogen, or nitrous oxyd. This gas is procured from nitrate of ammonia, which ought to be made by the operator: most of that purchased in the shops contains a small quantity of sal ammoniac, which as I know by experience, occasions a bubbling, a frothing, and a boiling over that not only injures the quality of the gas, but endangers the retort, and occasions a loss in quantity. These circumstances are well noted by Mr. Sadler, 15 Nicholson's Jour. 286.

The nitric acid should be carefully purified by nitrate of silver. It should then be saturated with carbonate of ammonia, and gently evaporated to crystallize. A moderate heat of a lamp from 400 to 450 Fahrenheit, suffices to decompose the salt. The gas should stand for an hour over water before it be used for respiration. I have taken six quarts without any effect, and in about two hours six quarts more, with the usual confused ideotish but exhilarating effect described by Mr. Davy.

This gas may be made, not so conveniently indeed or so pure, 1st, by exposing nitrous gas for a few days to iron filings: the filings abstract part of the oxygen, and leave nitrous oxyd. 2dly, By dissolving zinc or tin in nitric acid diluted with six times its weight of water.

PAGE 328. NO. 27.

Absorption of nitrous oxyd by water. The water should be previously boiled: it should be cooled without access of air: it absorbs half its bulk at common temperature: this furnishes a test of the air, for the nitrous oxyd is absorbed, and the contamination left unabsorbed: for this purpose the water should be about three times the quantity of the gas: when heated, the water gives out the gas unchanged: the impregnated water, does not change blue vegetable colours: it has a sweet taste: a faint but pleasant odour.

PAGE 335. NO. 28.

Gaseous oxyd of nitrogen, or nitrous oxyd, is not diminished by either oxygen or nitrous gas: a mixture of equal parts of hydrogen and nitrous oxyd detonates, nitrogen only remains: when the hydrogen is in less proportion than 39 to 40, nitric acid is also generated: nitrous oxyd also forms a combustible mixture with ammoniacal gas, of which 100 measures require for saturation 130 measures of nitrous oxyd: this gas is not absorbed by alkalies unless in a nascent state: animals die in it: it consists according to Davy of 36,7 oxygen and 63,3 nitrogen.

PAGE 364. NO. 29.

Chlorine or oxymuriatic acid gas. This substance was discovered by Scheele in 1774. Put into a retort, three parts by weight of common

salt, well mixed with one part by weight of manganese in fine powder, and two parts of oil of vitriol diluted with an equal bulk of water. It is best made in a tubulated retort. The first air that passes over, is the air of the retort, and some carbonic acid gas with which the manganese is usually contaminated. Instead of manganese, the red oxyd of mercury, called red precipitate may be used—or the brown oxyd, called precipitate per se—or common red lead (minium) or the puce-coloured (flea coloured, brown) oxyd of lead which is the per oxyd. These being substances containing much oxygen.

Also, common muriatic acid, or spirits of salt, may be substituted for the vitriolic (sulphuric) acid and water.

This gas being of a greenish yellow colour is called by Davy, *chlorine*.

It appears then, that whenever substances containing much oxygen, are exposed to the action of muriatic acid either ready formed and mixed with water, or in its nascent state, as when the substances are put together which are usually employed to form it, viz. sulphuric acid and common salt, the gas called *oxymuriatic acid gas* by one set of chemists, and *chlorine gas* by Davy and his followers, is produced.

Berthollet and all the chemists until the recent experiments of Gay Lussac and Thenard, and Davy, have conceived that this was a compound gas, formed by the union of muriatic acid to oxygen: 1st, because it is never produced except when muriatic acid is treated with substances containing oxygen. 2dly, because the oxygenated substances become deoxygenated by the process. 3dly, because this gas has all the properties that might be expected from a union of oxygen and muriatic acid gas: it destroys vegetable colours: it is converted into muriatic acid when mixed with hydrogen or with carburetted hydrogen, and exposed to solar light: it converts the carbonic oxyd into carbonic acid: nitrous gas is condensed by it in the same manner as by oxygen gas: it converts sulphurous acid gas into sulphuric acid: phosphorus burns brilliantly in it: so does the powdered charcoal of beech wood: so do the metals reduced to powder, or beaten into very thin leaves: when streams of this gas are passed through flowers of sulphur, an oxyd of sulphur mixed with muriatic acid is formed: this gas forms detonating compounds with alkalies: and in all these cases of seeming deoxygenation, the acid is changed from oxygenated muriatic, into common muriatic gas.

These experiments, which the presence of oxygen in this gas, so very easily explains, would seem to amount to full proof that oxymuriatic gas, is a compound of muriatic acid and oxygen: but the two following experiments go still nearer to demonstrate it.

Saturate water with oxymuriatic gas, fill a bottle with it: let a bent tube communicate with the inside of the bottle and a common pneumatic apparatus: the bottle should be transparent. Expose it to sun-shine; the liquor will gradually lose its colour, bubbles will separate which being collected will be found to be oxygen gas, and the liquor in the bottle will be common muriatic acid and water. Berthollet who made this experiment computed the oxygen of oxymuriatic acid to be 11 per cent. Chevenix makes it nearly double that; Gay Lussac states it at half the volume of the oxymuriatic gas: but the quantity is not now in question; for it is denied that oxygen can be separated from oxymuriatic acid.

When oxymuriatic gas is passed through pure or caustic potash (potash deprived of its carbonic acid by means of quick lime, and filtered) two salts are formed, the one, common muriate of potash, the other the hyper-oxymuriate of potash; for this last contains the whole oxygen which the gas contained. This salt, the hyper-oxymuriate of potash, when exposed to heat in a glass retort, yields 72 cubic inches of pure

oxygen gas from 100 grains, and about three cubic inches of nitrogen. Now, where does this oxygen gas come from, if the oxymuriate or chlorine gas contained none?

Sir Humphrey Davy however, in his late elements of chemical philosophy, has taken for granted; assumed it as a point established, that there are in nature two supporters of combustion, to wit, oxygen and chlorine: that chlorine, is a substance sui generis, simple, uncompounded, and containing no oxygen whatever: that the term oxymuriate, is founded on a false theory of its composition, and therefore is to be rejected

Scheele had suspected oxymuriate to be a simple substance, and Gay Lussac and Thenard had also published several experiments, that seemed to show that oxymuriatic gas *might* be considered as a simple substance forming common muriatic acid when united to hydrogen, but they did not renounce the common opinion.

The conjecture of Gay Lussac and Thenard was pursued by Davy, with his usual industry and ingenuity. The principal reasons assigned for the opinion he adopts, are in substance as follows:

1st. Oxygen has a very strong affinity to carbon: but when oxymuriatic acid gas is passed over red hot charcoal, although common muriatic gas is given out at first, in consequence of the hydrogen contained in the charcoal, yet the oxymuriate soon passes without alteration.

2d. When tin is combined with oxymuriatic acid, wherein it is supposed that the oxygen goes to oxydate the tin, and the common muriatic acid dissolves it, he could not procure this oxyd of tin by saturating the acid with ammonia: a ternary compound was formed.

3d. When phosphorus is treated with oxymuriatic acid, a compound is formed, similar to that which is made by distilling phosphorus with corrosive sublimate; but there is no decided abstraction of oxygen. When water is added to this mixture, phosphoric acid and muriatic acid are formed, the oxygen of the water making phosphoric acid, and the hydrogen of the water uniting to the chlorine and forming common muriatic acid.

4th. When this combination of phosphorus and chlorine was neutralized by ammonia, the product was not phosphoric acid and sal-ammoniac, but a ternary compound, undecomposable. The same was the case, with the sulphuretted muriatic acid formed by Dr. Thompson by passing oxymuriatic acid through flour of sulphur.

Lastly, common muriatic acid, is in all cases formed by the union of hydrogen with chlorine in equal volumes, and without any deposition of water. This union takes place, whenever hydrogen and chlorine are simply mixed together, and left exposed to the common light. Hence, Davy considers chlorine as a simple substance, combining as such with phosphorus, sulphur, the fixed alkalies, earths, and metals, and with all inflammable bodies, enabling with them, combustion to take place. He considers the common muriatic acid as formed of chlorine as its acidifying principle and hydrogen as its base: and when hydrogen is not present, in the form of a gas, the common muriatic acid can be procured from chlorine by the decomposition of water furnishing hydrogen. He denies that there is any proof of the existence of oxygen in oxymuriatic gas, or of water in the common muriatic acid gas, explaining all the apparent productions of oxygen from chlorine, by the decomposition of water, which in reality furnishes the oxygen, while its hydrogen uniting with chlorine forms common muriatic acid.

The supporters of the old theory on the contrary, account for the production of muriatic gas when hydrogen is mixed with chlorine, in this way. The hydrogen unites with the oxygen and forms water, which is

taken up as a necessary component part of, and goes to form the common muriatic acid gas, which is never found without it.

At this stage of the controversy, it is brought to a simple point wherein Sir Humphrey Davy on the one side, and Mr. Murray on the other, are at issue. If it be true as the former says, that common muriatic gas contains no water in its composition, and if, as appears to be the fact, no water is deposited or precipitated when hydrogen combines with oxymuriatic acid gas, then is there no proof that oxymuriatic gas contains oxygen, and the disappearance of the hydrogen, and the production of common muriatic acid gas are inexplicable, unless upon the hypothesis of Sir Humphrey Davy.

On the contrary, if muriatic acid gas, do hold water as a constituent in its state of gas, then the disappearance of the hydrogen, the abstraction of the oxygen from oxymuriatic gas, the disappearance of the water so formed, and the appearance of common muriatic gas as the consequence of this union of the oxygen and hydrogen into water, is all plain, simple, and intelligible on the theory commonly received; and Sir Humphrey Davy's explanations must fall to the ground. The whole controversy is now reduced to a beautiful case of chemical special pleading: the parties are at issue on a single fact; of which the *onus probandi* rests on Mr. Murray and the defenders of the old doctrine; for Sir Humphrey Davy is not bound to prove the negative.

Accordingly Mr. Murray proceeds to show that common muriatic gas, *does* hold water: but previous to so doing, he attempts to show, that from known chemical analogies, there is no reason to expect that charcoal should take the oxygen from oxymuriatic acid.

When oxymuriatic acid is decomposed by hydrogen, the oxygen goes to form water, and the water formed, is taken up by the muriatic acid gas. When oxymuriatic acid is decomposed by metals, the oxygen unites with the metal, which then becomes soluble in the muriatic acid which remains. But when oxymuriatic gas is passed over red hot charcoal, the union of oxygen and carbon forms no water, without which the muriatic acid cannot exist: nor can the oxyd of carbon, or the carbonic acid aid the divellant affinities, for they have little or no affinity with muriatic acid. Hence, the muriatic acid cannot appear, the oxygenated muriatic acid therefore cannot be decomposed by charcoal. But when hydrogen instead of carbon is presented to oxygen, the water formed, unites instantly to the remaining product and forms common muriatic acid gas.

Still however this explanation proceeds on the supposition that common muriatic gas, *does* hold water in solution, and as a constituent. Murray then goes on to detail some experiments of Gay Lussac, and some of his own, to show that this last mentioned gas is such as he states it to be.

1. It is agreeable to the analogy of all the other acids: the sulphuric, the nitric, the phosphoric, the fluoric acids contain water, of which they cannot entirely be deprived; and why should not the muriatic?

2. When muriatic acid gas unites to metallic oxyds, water appears; so when sulphuric, nitric, phosphoric, fluoric acids unite to metallic oxyds water is separated. In the latter cases, this appearance admitted as proof that water was combined with the acids; why not in the former?

3. Gay Lussac and Thenard have proved, that muriatic acid gas always contains 0.25 of its weight of water. By decomposing oxymuriatic gas by ammoniacal gas, they found reason to conclude that oxymuriatic gas contains half its bulk of hydrogen; and of course according to the known proportions in which oxygen and hydrogen combine to form water (viz. two in bulk of hydrogen to one of oxygen) they concluded that it must unite precisely with its volume of hydrogen.

it does so: therefore muriatic acid does contain 0.25 of its weight of water, or with more precision according to their experiment 0.245.

4. They endeavoured to abstract the oxygen of the oxymuriatic acid gas, and procure the muriatic gas free from water: they pursued the methods already noted with the sulphurets, phosphorus and charcoal, but they could not by these means decompose the oxymuriatic acid, and they could not procure the muriatic acid free from water.

5. They could not decompose the oxymuriatic gas, when *dry*, by *dry* sulphurous acid gas, by carbonic oxyd, by nitrous or by nitric oxyd; but they easily decomposed it when moisture was admitted.

It is true in these experiments they took for granted the common theory that oxygen is a component part of oxymuriatic acid: still the fact remains that they could obtain no muriatic acid without water, and they could always obtain it when moisture was present.

To free these experiments from ambiguity, Murray made the following *experimentum crucis*.

"Water is produced, when muriatic acid gas combines with a metallic oxyd: Mr. Davy says it is formed by the oxygen of the oxyd combining with the hydrogen of the acid." If however there is any case of a substance which does not contain oxygen, combining with the acid, this supposition is necessarily precluded; and if water is produced in such a combination, it must be inferred to be derived from the acid. Ammonia is a substance of this kind; and to decide on the truth of these two systems, it is only necessary to ascertain the fact, whether water is contained in the salt which it forms with muriatic acid gas.

"I combined over dry mercury, dry ammoniacal gas with muriatic acid gas, and having collected the salt formed, I exposed it to heat in a retort, and found water to be expelled and condensed in the neck of the retort. This proved therefore, its existence in the salt; and from the volatility of muriate of ammonia, it was not possible to raise the heat so high as to expel all the water it might contain. I therefore sublimed the residual salt through ignited charcoal, and found that an additional portion of water was separated. The whole quantity I found from the details of the experiment, amounted to about one-6th nearly of the weight of the acid, and there can be no certainty, that all the water is even in the second stage of the experiment expelled from the salt. (Nicholson's Jour. vol. xxxi, p. 126.)

"The existence of water in muriatic acid gas is thus established: the water which is obtained in other combinations of the acid with salifiable bases, must be equally considered, as that which *has existed* in union with the acid; and the hypothesis of its *formation* cannot be maintained.

"Mr. Davy has supposed however, that the water which, from a repetition of the experiment, he admits is produced, is derived from the atmosphere, the salt imbibing it, in the short time during which it is exposed to the air in conveying it from the vessel wherein it is formed, to the retort in which it is exposed to heat, and experiments have been stated on his authority, in which when the salt was heated without exposure to air, no water was obtained (xxxix Phil. Mag. xxxi Nich. Jour.) This supposition is altogether inadmissible, for muriate of ammonia, is not a deliquescent salt, but remains perfectly dry when exposed to air in a common state of dryness: and there is not an example

* Hence the neutral formed will be an oxymuriate: for when hydrogen is abstracted from common muriatic acid, according to Davy, oxymuriatic acid is produced.

in chemistry of a substance soluble in water imbibing it with any celerity from the atmosphere, without continuing to attract it until it is dissolved: the very force of attraction which gave rise to the first effect, causing a continuance of it, until that equilibrium is attained which produces solution.

"It is accordingly proved by subsequent researches that this supposed source of fallacy has no existence. Dr. Bostock and Dr. Trail have performed the experiment in such a manner as to exclude the agency of the atmosphere. The ammoniacal gas, and the muriatic acid gas were separately carefully dried, and were combined in a flask furnished with a bent tube. After the combination was completed, the tube was adapted to the flask, and the latter was turned over, so that the extremity of the former was kept below the surface of the quicksilver. The flask was imbedded in a charcoal furnace, and gradually heated so as to sublime the salt. When it was about half sublimed, a dew was observed to form at the upper part of the curvature of the tube, which increased so, that at one period it occupied a zone around the tube of about an inch in width, and some globules of water were formed; and when this was driven forward by increasing the heat, a deposition of moisture was observed at the end of the tube. (Supplement to xxxi Nich. Journ.) An experiment resting upon authority so unexceptionable, and evidently conducted with every precaution to ensure accuracy, must be regarded as conclusive. I have also found by an experimental investigation, of which the details will be speedily published, that water is obtained as Dr. Bostock and Trail found, when the salt formed by the composition of muriatic acid and ammonia is submitted to heat without exposure to air---that the quantity produced is apparently as considerable as when it has been previously exposed---that this salt does not absorb humidity from the atmosphere, so as to afford the water which it yields when submitted to heat---and that even when the water expelled from it is submitted to its action, it does not again absorb it, so as to afford thereby any explanation of the result of the experiment. I cannot therefore but regard this result, as sufficiently established, and it has been admitted, that if it be established, it is conclusive on the subject of this controversy. See supplement to the second edition of Murray's Chemistry, p. 108."

To this apparently decisive experiment, I have heard as yet of no reply.

The proportion of oxygen in oxymuriatic acid, is stated
By Berthollet at 11 per cent.
By Chevenix 16.
By Gay Lussac 22.92.
By Dalton 24.

The proportion therefore cannot yet be considered as ascertained. Might it not be arrived at, by ascertaining the quantity of hyperoxymuriate of potash formed from a given proportion of gas, and the quantity of oxygen yielded by the salt?

Since one measure of oxymuriatic gas consumes exactly one measure of hydrogen gas---and one measure of oxygen gas consumes two measures of hydrogen gas, it follows that oxymuriatic gas must contain half its volume of oxygen gas: and from the same result it follows, that muriatic acid gas must contain 0.25 of combined water. (Murray.)

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Combustion. I do not see that sensible heat and flame are at all necessary to enter into the chemical notion of combustion. Whether the heat separated when oxygen unites with a combustible body, be attended with heat manifest to our senses from the suddenness and violence of the union, or whether it be so gradually evolved as not to affect our senses, is of no consequence to the theory. That *combustion* is the term properly applicable to the union of oxygen and an inflammable body, appears to me as well settled as any part whatever of chemical language or chemical theory.

Accum takes for granted that caloric and light are always emitted during combustion, and that the oxygen gives out the caloric, and the combustible the light (389.) It may be true that the light is a component part of the inflammable body; and some of the reasons assigned by Accum render it probable: but there is as yet no satisfactory proof of it.

As to the caloric evolved, it is usually ascribed to the oxygen whose caloric is separated when this gas combines with a combustible and becomes fixed. My own notion is, that it is to be ascribed in a fivefold proportion to the combustible itself. Here is the proof. The specific heat of water being 1. that of common air is 1.79, of carbonic acid 1.05, of nitrogen .79, of oxygen 4.75, of hydrogen 21.4. Of course the proportions of heat evolved is fairly ascribable to that substance which when condensed into a solid can furnish the most.

Facts seem at present to point out the following conclusions. 1st. There is but one body in nature capable of being burnt, hydrogen; the phlogiston of the older chemists. 2d. There is but one body in nature capable of supporting and maintaining combustion, oxygen. 3d. When the union between these two is sudden and violent heat and flame are produced, obvious to the senses: when slow and gradual, the heat and light evolved are not obvious to the senses which are very limited, imperfect and inaccurate tests. 4th. When oxygen and hydrogen uniting together so as to produce combustion, become solid from a gaseous state, the heat or caloric unnecessary to the new compound, is given out, and becomes the heat of combustion: of which it is presumable that the hydrogen furnishes the greater part, its latent heat as well as its specific heat being so much greater, for it is by far the lightest of the gases. 5th. As the colour of the flame during combustion depends on the combustible—as all vegetable colour seems greatly dependant upon solar light—as it is reasonable to expect that the light evolved during combustion, must proceed from one or other of the two bodies which unite during combustion, there is room for conjecture that light is united to combustible bodies in a solid state; but whether to the hydrogen, or concomitantly with it, we have no facts to determine. 6th. That animal heat is not exclusively owing to the absorption of oxygen into the blood, but that as heat is either evolved or absorbed in every possible case of chemical union, evolution and absorption of heat is perpetually going forward in every part of the body, particularly in the digestive and glandular or secreting part of our system.

If this account be true, it will lead us to conclude that oxygen and hydrogen will unite in other proportions beside that which forms water.

T. C.

THE END.

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